Harnessing arbuscular mycorrhizal fungi (AMF) for quality seedling stock production of *Tectona grandis* Linn. and *Swietenia macrophylla* King.

By

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(2013-17-109)

THESIS

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2015

DECLARATION

I hereby declare that this thesis entitled "**Harnessing arbuscular mycorrhizal fungi (AMF) for quality seedling stock production of *Tectona grandis* Linn. and *Swietenia macrophylla* King**" is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled **"Harnessing arbuscular mycorrhizal fungi (AMF) for quality seedling stock production of *Tectona grandis* Linn. and *Swietenia macrophylla* King"** is a record of research work done independently by **Mr. Ajeesh, R. (2013-17-109)** under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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We, the undersigned members of advisory Committee of **Mr. Ajeesh, R. (2013-17-109)** a candidate for the degree of **Master of Science in Forestry** agree that this thesis entitled **"Harnessing arbuscular mycorrhizal fungi (AMF) for quality seedling stock production of *Tectona grandis* Linn. and *Swietenia macrophylla* King"** may be submitted by **Mr. Ajeesh, R. (2013-17-109)**, in partial fulfillment of the requirement for the degree.

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EXTERNAL EXAMINER

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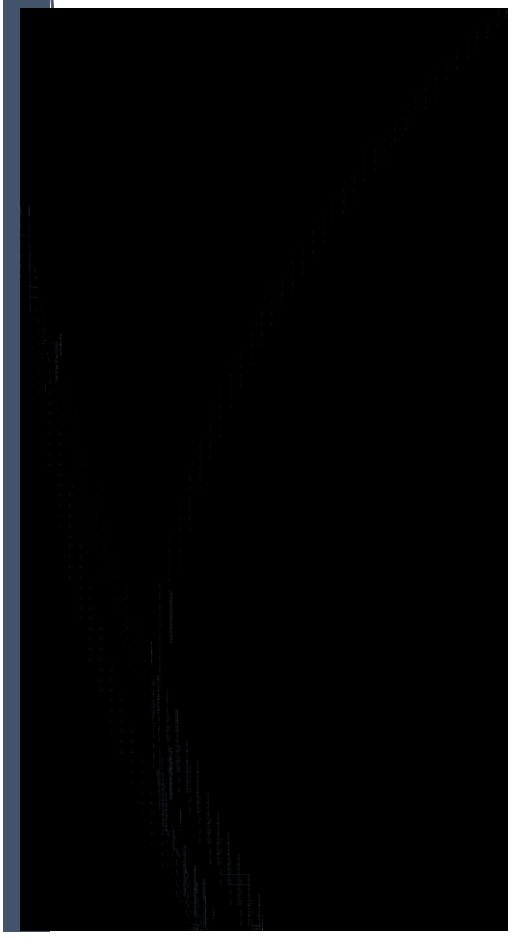


1. INTRODUCTION

Arbuscular mycorrhizal fungi (AMF), a group of obligate biotrophic fungi belonging to the Phylum *Glomeromycota* are among the oldest fungi in terrestrial systems on earth. The symbiotic relationship of these fungi with plants is assumed to have played an essential role in the establishment of (pre)vascular plants on the land. Around 230 morphospecies of these fungi have been identified and described (Schubler, 2013).

Symbiotic associations of AMF and plant roots are widespread in the natural environment and can provide a range of benefits to the host plant. These include improved nutrition, enhanced resistance to soil-borne pests and diseases, improved resistance to drought, tolerance to heavy metals and better soil structure (Gosling *et al*., 2006). Presence of AMF can significantly increase root surface area by production of extensive hyphae, increase transpiration, reduce leaf temperature and restrain the decomposition of chlorophyll (Abbaspour *et al*., 2012). The AMF host obtains maximum benefit when the mineral nutrient regime is least favourable for growth (Ezawa *et al*., 2002). In turn, plants direct 4% to 20% of photoassimilate to mycorrhizas (Ruissen, 2013). Hyphae work as conduits that transport carbon from plant roots to other soil organisms involved in nutrient cycling processes. Though the AMF association can offer multiple benefits to the host plant, it may not be obviously mutualistic at all points in time, and it is possible under some conditions, host plant loose carbon with no apparent benefit. In some cases, it can even cause a decline in growth (Lerat *et al*., 2003).

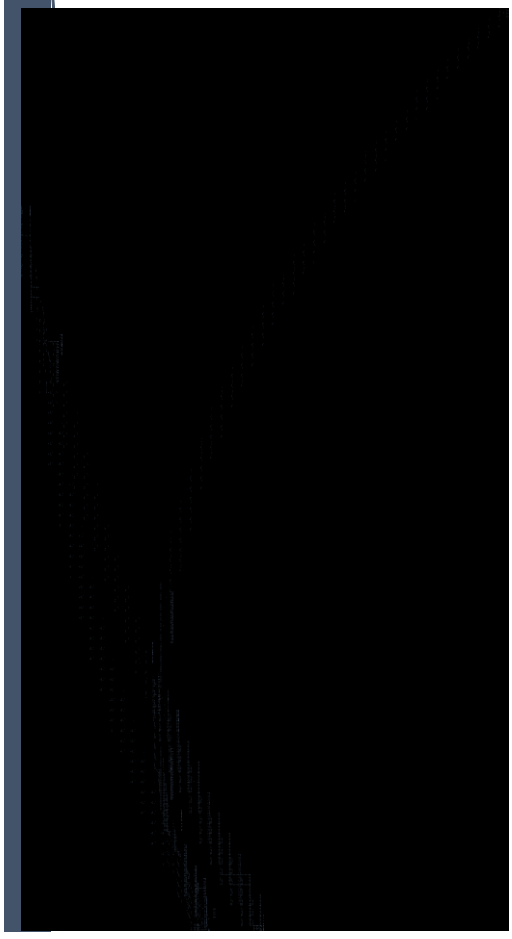
In many forest tree seedlings, the inoculation of AMF was beneficial (Dutt *et al*., 2013; Binu *et al*., 2015) resulting in seedlings of higher quality. The high percentage of root colonization in AMF treated seedlings was directly correlated with an improved growth and physiology (Dutt *et al*., 2013). In all forest tree seedlings examined, AMF resulted in a higher biomass, height, collar diameter, root colonization percent and quality index. Knowledge about AMF in forest species is limited with regard to their diversity, molecular mechanism of symbiosis and inoculation. Arbuscular Mycorrhizal

Fungi is an unexploited potential biofertilizer in forest nurseries which can be utilized for quality tree seedling production.

Teak (*Tectona grandis* Linn.) and mahogany (*Swietenia macrophylla* King.) are the most important timber species that are widely used for raising plantations and afforestation in Kerala. These require a relatively long nursery period lasting about one year. The goal of forest tree nursery practices is to produce high quality seedlings. Evolving appropriate nursery management strategies to reduce the long nursery period by enhancing seedling growth has been the basic challenge. Among the various silvicultural options, early tree nutrition practices have bagged considerable attention in the recent times in view of their long standing effect on tree growth and productivity. However, the species is still poorly studied in relation to its management in plantations and its physiological responses to AMF applications. Especially, appropriate organic fertilizers in proper dosages promote biomass production and physiological activities of seedlings. However, studies on standard screening of AMF level of inoculation regimes on most tropical trees are meagre. Especially, such information pertaining to mahogany and teak is lacking from Kerala. Screening and standardization of AMF levels inoculation is necessary for any afforestation programme as expenditure on nursery takes itself a major portion of plantation cost. The cost can however, be reduced by evolving suitable and desired nursery practices on scientific lines.

The present study has been formulated to assess the impact of inoculation potential of selected AMF on growth and quality of *T. grandis* and *S. macrophylla* seedlings.

REVIEW OF LITERATURE



2. REVIEW OF LITERATURE

Arbuscular mycorrhizal fungi (AMF) is the most ancient and widespread form of beneficial microorganism. Paleobotanical and molecular sequence data suggest that the first land plants formed associations with Glomalean fungi from the Glomeromycota about 460 million years ago (Redecker et al., 2000). Around 230 morphospecies of these fungi have been identified and described (Schubler, 2013). The study of AMF has fundamental and practical importance. AMF is able to make symbiotic relationships with many plants including important agricultural crops. AMF inoculates the root surface of the host plant to acquire carbon and help the host plant take up phosphorous and other nutrients from the soil. Mycorrhizal plant gains better compared to non-mycorrhizal plants. The process of root inoculation by the fungi is made of complex stages including spore germination, hypha differentiation, aprosurium formation, root penetration, intercellular growth, arbuscule formation and nutrient transfer (Harrier, 2001). When in symbiotic relationship with plant roots, is the significant increase in root surface area due to the production of extensive hypha helping plants grow under relatively harsh conditions, such as drought stress (Al-Karaki et al., 2004) and nutrient deficiency conditions (Marschener and Dell, 1994). The hypha of AMF, which are 2-3 times finer than even the finest root hairs (Jakobsen, 1995) may penetrate very fine soil pores in compacted soils. AMF may increase plant tolerance to biotic and abiotic stresses. Symbiotic associations of AMF and plant roots are widespread in the natural environment and can provide a range of benefits to the host plant. These include improved nutrition, enhanced resistance to soil-borne pests and disease, improved resistance to drought, tolerance of heavy metals and better soil structure (Gosling *et al*., 2006).

In many forest tree seedlings, the inoculation of AMF was found beneficial (Dutt *et al*., 2013; Binu *et al*., 2015) resulting in seedlings of higher quality. The high percentage of root colonization in AMF-treated seedlings is found to be directly correlated with an improved growth and physiology (Dutt *et al*., 2013). In many forest tree seedlings examined, AMF resulted in a higher biomass, height, collar diameter, root colonization percent and quality index. Knowledge about AMF in forest species is limited with regards to their diversity, molecular mechanism of symbiosis and

inoculation. Arbuscular mycorrhizal fungi are an under-exploited potential biofertilizer (Gopal *et al*., 2005) in forest nurseries which can be utilized for quality tree seedling production.

2.1. DIVERSITY OF AMF

The obligate biotrophic fungi belonging to the *Glomeromycota* are among the oldest fungi in terrestrial systems on earth (Brundrett, 2002). The symbiotic relationship of the *Glomeromycota* with plants is assumed to have played an essential role in the establishment of (pre)vascular plants on the land masses that took place about 460 million years ago in the geologic period Middle Ordovician (Redecker *et al*., 2000) as supported by evidence from fossil material. The glomeromycotan fungi develop symbiotic relationships with the majority of vascular plants in almost all habitat types (Wang and Qiu, 2006).

Around 230 morphospecies of these globally important fungi have been identified and described so far (Schubler, 2013), which is a remarkably low number for such an old and widely distributed fungal taxon (Rosendahl, 2008). Recent introduction of molecular taxonomy has revealed, a far greater genetic diversity than morphological characteristics make visible. In India, Bakshi (1974) was the first to publish an account of 14 spore types of AMF; 102 AMF species have been reported from India (Manoharacharchary *et al*., 2005)

2.1.1. Diversity in Kerala

A KFRI survey conducted in 26 plantations of Acacia in Kerala state of India to assess the status of mycorrhizal association was revealed AMF association with the species. The extent of colonization by AMF was very high (90 to 100%) in majority of the plantations. This indicated that acacia is mycorrhizas-dependent for its growth and establishment (Sankaran *et al*., 1993; Mohanan, 2003). While increasing the depth of soil there is decreases in there number of spores in evergreen forests and moist deciduous forest of Western Ghats (Mohanan, 2002).

In a study done at KAU, among the different locations of wilt infested areas of Kerala, the maximum mycorrhizal population was observed in Eruthyampathy of

Palakkad district. Among these, *Glomus* sp. was the most predominant in Thrissur and Palakkad districts indicating wide adaptability to various ranges of soil and environmental factors. The total AMF spores in the samples collected ranged from 26-1012 spores/10 g of soil. The maximum (1012) number of AMF spores was recorded in case of brinjal from Eruthyampathy and the minimum AMF spores (26) were recorded with the rhizosphere soil of chilli from Chittoor (low wilt area) (Gopal *et al*., 2005). The *Glomus*, *Acaulospora*, and *Sclerocystis* spp. were the major AMF genera observed. In a similar study, conducted in Northern Kerala reported the presence of AMF isolates belonging to genus *Acaulospora*, *Glomus*, *Sclerocystis* and *Gigaspora* (Harikumar and Potty,1999).

A survey conducted in medicinal plants in different places in Thrissur, Kerala, revealed that all the medicinal plants showed AM colonization in their roots and the spores of *Glomus mosseae, Gigaspora, Acaulospora* and *Sclerocystis* were present, with *Glomus mosseae* and *Gigaspora* dominating (Sudha and Ammani, 2010). Another survey conducted in medicinal plants in different places in Kannur (Muthuraj *et al*., 2014) revealed AMF colonization ranged from 24-81% and AMF spore population with a range of 140 to 620 in 100 g of rhizosphere soils. Totally 35 AM fungal species were isolated which belongs to four genera (*Aculospora*, *Gigaspora*, *Glomus* and *Scutellospora*) and among them *Glomus* was dominant genera.

2.2. AMF AND ITS IMPORTANCE

Arbuscular Mycorrhizal Fungi is able to make symbiotic relationships with many tree species. Arbuscular Mycorrhizal Fungi inoculated root surface of the host plant helps to acquire carbon and take up phosphorous and other nutrients from the soil. Symbiosis is useful for the plant because phosphorous is necessary for plant growth and development, especially under phosphorous deficient conditions (Harrison and Van Buuren, 1995). The process of root inoculation by the fungi is made of complex stages including spore germination, hypha differentiation, aprosurium formation, root penetration, intercellular growth, arbuscule formation and nutrient transfer (Harrier, 2001). Arbuscules are branched hypha, found inside root cells from where nutrient exchange takes place between fungi and the host plant (Van Duin *et al*., 1989; Entry *et*

al., 2002; Troeh and Loynachan, 2003). As roots develop, a condition for inoculation by AMF improves and the carbohydrates are used by AMF for growth (extension of the hypha).

AMF may increase plant tolerance to biotic and abiotic stresses (Subramanian and Charest, 1997). One of the unique characteristics of AMF, when in symbiotic relationship with plant roots, is the significant increase in surface area due to the production of extensive hypha helping plants grow under relatively harsh conditions, such as drought stress (Al Karaki *et al*., 2004) and nutrient deficiency conditions (Marschener and Dell, 1994).

2.2.1. Nutrient uptake

The capacity of plants to acquire nutrients is affected by many factors. The formation of AMF can increase the capacity of plants to acquire nutrients from the soil (Smith and Read, 2008). The fungi do this by growing beyond the nutrient depletion zones that typically form around roots, and by greatly increasing the absorptive surface of the root system. Their rapid growth and high plasticity enables the fungi to exploit nutrient patches in the soil, and to better respond to the tremendously complex spatio-temporal dynamics of soil nutrients (Tibbett, 2000; Facelli and Facelli, 2002). Arbuscular Mycorrhizal Fungi are able to take up nutrients in inorganic forms (Marschner and Dell, 1994). There is some evidence to suggest that AMF may access nutrients from organic sources (Hodge *et al*., 2001; Hodge and Fitter, 2010), this most likely occurs following the mineralization of nutrients in organic matter (Smith and Smith, 2011). Irrespective of the mechanisms involved, it is likely that AMF will be important in helping plants to acquire nutrients released due to decomposition. Although insights have been gained into how compost addition affects the formation of AMF, relatively few studies have considered impacts on the functioning of AMF (Caravaca *et al*., 2003; Puschel *et al*., 2008; Roldan *et al*., 2006). Arbuscular Mycorrhizal Fungi has the potential to promote plant nutrition and growth, and reduce nutrient leaching. Enhanced plant phosphorus (P) uptake is generally considered the main benefit of AM to plants (Abbott and Robson, 1984). Effects of P supply on the

formation of AMF are especially relevant to farming systems where large amounts of inorganic fertilizer are added to the soil.

AMF enhance the uptake of nitrogen (Leigh *et al*., 2009), zinc (Ryan and Angus, 2003; Seres *et al*., 2006), copper (Toler *et al*., 2005) and iron (Kim *et al*., 2009) among others (Ryan *et al*., 2004). The evidence for multifunctionality in AMF with respect to plant nutrition (Smith *et al*., 2004; Facelli *et al*., 2009; Leigh *et al*., 2009; Smith and Smith, 2012) has yet to show whether observed differences among AMF are consistent. Variation in plant micronutrients may be also due to differences among AMF. There is mounting evidence for functional specialization among AMF (Hart and Reader, 2002; Smith *et al*., 2004; Cavagnaro *et al*., 2005; Powell *et al*., 2009; Thonar *et al*., 2011). Also, the AMF may be important for a wide variety of nutrients. Overall, the effect of AMF on plant micronutrient nutrition is mixed: there are reports of enhanced effects (Karagiannidis *et al*., 2007; Javaid, 2009; Leigh *et al*., 2009; Veresoglou *et al*., 2010), diminished effects (Li *et al*., 2008) and no effects (Aryal *et al*., 2003; van der Heijden *et al*., 2006).

2.2.1.1. Phosphate transport

Thus P is a most important ‘currency’ in the symbiosis. After absorbing P from the soil solution, the fungi first incorporate it into the cytosolic pool, and the excess P is transferred to the vacuoles. The vacuolar P pool probably plays a central role in P supply to the plant. The main forms of inorganic P in fungal vacuoles are orthophosphate and polyphosphate, but organic P molecules may also be present. Long distance translocation of P from the site of uptake in the external mycelium to the site of transfer to the plant is probably achieved via transfer of vacuolar components. This transport would be mediated either by protoplasmic streaming or the motile tubular vacuole-like system. The site of release of P into the interfacial apoplast and thence to the plant is most probably the fungal arbuscules (Ezawa *et al*., 2002).

AMF improves the survival and growth of most plants in natural communities (Ibijbijen *et al*., 1996). Their ability to increase growth and yield by improving nutrient uptake makes them very important (Smith and Read, 1997). The function of all

mycorrhizal systems depends on the ability of the fungal symbiont to absorb inorganic and organic nutrients available in soil (Marschner and Dell, 1994).

2.2.2. Disease control

The presence of AMF in the root system of plants is well known to improve plant health and growth (Auge, 2001). A plant with a well established symbiont is better off because of increased resistance to various stress factors. The intimate interrelationship between the mycorrhizal symbiont and the plant ensures that it will be highly responsive to management practices (Sikora, 1992). Often, AMF-colonized plants are less infected by pathogens and show lower disease incidence than the non-colonized plants (Torres-Barragan *et al*., 1996). This prophylactic ability of AMF could be exploited to improve plant growth and health. Several reports have provided evidence of AMF inoculation as a means of biological control against soil-borne diseases (Idoia *et al*., 2004), but only few authors have reported the role of AMF against shoot or stem diseases (Vestberg *et al*., 1994).

It has been postulated by several workers that, the earlier the AMF establish symbiosis with host plants, the sooner the host plants get benefited from this mutualistic relationship in terms of improved growth and reduced incidence of diseases (Krishna *et al*., 2005). This could be attributed to better compensation for the damage caused by the pathogen (Nogales *et al*., 2009) through increased capacity for nutrient uptake by the AMF and plant association, which may allow host plants to be more vigorous, and consequently more resistant or tolerant of pathogen attacks (Azcón-Aguilar *et al*., 2002).

2.2.3. Water uptake

AMF have the ability to affect plant water relations (Wu and Xia, 2006; Heidari and Karami, 2014). Arbuscular Mycorrhizal Fungi often alter rates of water influx and efflux in host plants, thus affecting tissue water content and leaf physiology (Boomsma and Vyn, 2008). One primary impact of AM symbiosis involves changes in stomatal conductance (*gs*) and transpiration (T), with T typically higher and *gs* frequently unaffected or greater during drought stress in AM relative to non-AMF plants.

Measured reductions in soil moisture content indicate that root systems of AMF plants often dry soils at a faster rate and more thoroughly than root systems of non-AMF plants. These affect likely results from either the greater evaporative surface area (i.e. larger above-ground biomass) or more extensive root systems observed in AM relative to non-AM plants. However, it may also result from the adherence of AM hyphae to soil particles, thus improving contact with the soil solution (Boomsma and Vyn, 2008). Enhanced drying by AM plants may also be associated with the access of hyphae to small pore spaces inaccessible to host roots and root hairs (Ruiz-Lozano, 2003) and the subsequent uptake of water by AM mycelia for the maintenance of physiological activities (Sa´nchez-Dı´az and Honrubia, 1994).

2.2.4. Stress control

Arbuscular Mycorrhizal Fungi are renowned for their exchange for photosynthetic carbon from their host, improved plant growth through increased nutrient uptake and enhanced plant tolerance against abiotic and biotic stress (Gaur and Adholeya, 2004; Smith and Read, 2008), such as salinity stress, heavy metal contamination, and desert conditions (Cantrell and Linderman, 2001; Feng *et al.*, 2002; Zhu *et al*., 2010). They have some unique properties making them beneficial to the host plant under different stresses. Arbuscular Mycorrhizal Fungi are able to produce a very extensive network of hyphae in the soil when in symbiosis with the host plant. The intraradical colonization of plant roots by AMF results in the formation of some specialized structure, including arbuscules (the organelle for the exchange of nutrients with the host plant) and vesicles (the storage organelle), which can significantly enhance the absorbing capacity of the root for water and nutrients (Rillig and Mummey, 2006).

Arbuscular Mycorrhizal Fungi allow plants to cope with both biotic and abiotic stresses. They may help to fight off verticillium wilt (Garmendia *et al*., 2004), alleviate certain nutrient deficiencies, improve drought tolerance, overcome the detrimental effects of salinity and enhance tolerance to pollutants (Turkmen *et al*., 2005). Rehabilitation of disturbed sites tends to attract ruderal non-mycotrophic or facultatively mycotrophic plants, which preclude the survival of mycotrophic seedlings and the introduction of mycorrhizal propagules (Reeves *et al*., 1979). The extensive

activity and survival potential of AMF in most naturally occurring plant populations on undisturbed soil are immediately obvious from an examination of the roots of the vegetation present. AMF have not yet been cultured axenically and are generally considered to be obligate symbionts in plants.

2.3. AMF INFECTION

The obligate biotrophic character of the AMF has always been a challenge in the study of these fungi. The requirement for establishing a symbiosis on a living plant makes these studies time consuming and limits experimentation. Requena *et al*. (2007) proposed the chemical signals exuded by the plant, such as flavonoids and strigolactones, together with surface or thigmotropic signals from the rhizodermis are possibly recognized by receptor proteins associated to the fungal plasma membrane. Signal exchange between the plant root and the hyphae of AMF before infection. Roots release a branching factor that induces alterations in the growth pattern of the fungus. In turn, the fungus releases a diffusible signal that is recognised by the plant and that leads to symbiosis-related gene activation.

Plants have been shown to direct 4% to 20% more photoassimilate to mycorrhizal root systems. The AM symbiosis therefore determines the flow of huge quantities of carbon worldwide an estimate of 5 billion tons of carbon annually may be reasonable (Bago *et al*., 1999). The asymbiotically growing AMF does contact a host root, a series of signaling events occurs between the partners, which leads to the “acceptance” by the host root of the AMF as a symbiont (Bucking and Shachar-Hill, 2005). The fungus then develops extensively between and within root exodermal and cortical cells, and forms intraradical structures, including arbuscules and lipid-rich vesicles.

2.4. EFFECT OF AMF ON TREE SEEDLINGS

Artificial inoculation with mycorrhizal fungi in the nursery is used to increase seedling performance in situations known by researchers and managers to have consistently positive results. In general, mycorrhizal inoculation resulted in a significant increase in plant height, stem girth, plant biomass and plant phosphorus content of teak seedlings (Rajan *et al*., 2000). Host preference among AM fungi has been reported by

earlier workers (McGraw and Schenck, 1981; Vasanthakrishna *et al*., 1995). Hence the need for selecting efficient AM fungi that can be used for inoculating different mycotrophic plants has been stressed (Jeffries, 1987; Bagyaraj and Varma, 1995). The present study with an objective of screening for an efficient AM fungus for teak seedlings has also resulted in varied plant growth responses to different AMF.

Rajan *et al* (2000) screened selected AMF for their symbiotic efficiency with *Tectona grandis*. Teak plants grown in the presence of AMF showed a general increase in plant growth parameters like plant height, stem girth, leaf area and total dry weight as against those grown in soils uninoculated with AM fungus. Among that *G. macrocarpum* significantly enhanced the plant height as compared to all other treatments except for *G. margarita*. However, seedlings raised in the presence of G. leptotichum had a significantly higher stem girth compared to all other treatments excepting G. *fasciculatum*. The total photosynthetic area expressed as the leaf area was significantly more in plants grown in the presence of *G. leptotichum*. This increased leaf area and enhanced nutrient content in seedlings colonized by *G. leptotichum* have probably resulted in significantly higher biomass observed compared to other treatments.

G. mosseae is the most promising and the best AMF symbiont for inoculating *Azadirachta indica* seedlings in the nursery (Sumana and Bagyaraj, 2003). Plant height, number of leaves and stem girth were significantly greater in plants inoculated with G. *mosseae* when compared with uninoculated plants. Plant biomass was enhanced by about 70% due to G. *mosseae* inoculation compared with uninoculated plants. Shoot and root biomasses were also significantly higher in plants inoculated with G. *mosseae* and the lowest biomass was observed in uninoculated seedlings (Sumana and Bagyaraj, 2003). Such an increase in biomass was reported by Vasanthakrishna *et al.* (1995) in *Casuarina equisetifolia* and Rajan *et al.* (2000) in *Tectona grandis* when inoculated with efficient VAM fungi. Similar observations were reported in *Dalbergia sissoo* which showed highest biomass content because of inoculation with G. *fasciculatum* (Sumana & Bagyaraj 1996).

Mycorrhizal symbiosis significantly improved plant growth performance, such as plant height, stem diameter, shoot, root or total dry weight compared with the non-AMF *Prunus persica* seedlings and the best in the *G. mosseae* treatment. Compared with the non-AMF treatment, plant height, stem diameter, shoot, root or total dry weight was significantly increased by 30.3%, 17.2%, 34.4%, 64.5% or 45.4% respectively with the inoculation of *G. mosseae* (Wu *et al*., 2011). The control seedlings had greater height, leaf area and dry matter in *Azadirachta excelsa* seedlings treated with *G. mosseae* and *S. calospora*. The control recorded higher growth parameters-height 36 per cent; leaf area, 39 per cent; total dry matter production, 14 per cent (Huat *et al*., 2002). Ananthakrishnan *et al*., 2004 *Anacardium occidentale* seedlings were inoculated with three species of AMF viz. *G. aggregatum*, *G. fasciculatum* and *G. mosseae.* Among that *G. fasciculatum* has significantly greater stem girth, number of functional leave and internodal length than the uninoculated plants.

Inoculation with all the three AMF (*G. occultum, G. mosseae* and *G. aggregatum*), resulted in significant increase in shoot height, diameter and leaf area of *A. mangium* compared to the control plants (Ghosh and Verma, 2006). *G. occultum* inoculated seedlings had higher biomass than seedlings inoculated with other AMF species. Enhanced growth of *Acacia holosericea* was recorded when the plants were inoculated with *Glomus intraradices* (Duponnois and Plenchette 2003 and *G. aggregatum* (Duponnois *et al.* 2001). AMF with *D. sissoo* stimulates plant growth under glasshouse conditions, which could be of importance for its survival and growth in natural conditions (Bisht *et al*., 2009). There were variations in height, number of leaves, leaf area, shoot weight and relative water content of *Santalum album* seedlings due to AMF inoculation (Binu *et al*., 2015) and best performed is *G. mosseae* under partial shade.

Mycorrhizal inoculation are no always equally infective to any one plant species and they certainly vary in their physiological interaction with different plant and hence in their effects on plant growth. The decreases in growth of *Azadirachta excels* seedlings was found when AMF species was introduced in the unsterile soil suggesting that introduced species are less effective than the native species. Another explanation is

the existence of antagonistic relationship between the native and of tropical trees nonsterile soils have also reported previously (Cuenca *et al*., 1990; Huat *et al*., 2002).

Neem seedlings inoculated with AMF with sub-optimal levels (Muthukumar *et al*., 2001). Although, the results of this study generally agree with previous reports on the positive growth response of tree seedlings to AM fungi in unsterile soil (Young 1990; Michelsen 1993), it contradicts reports where indigenous AM fungi were found to be ineffective or less effective (Bagyaraj *et al*. 1989; Reena and Bagyaraj 1990) compared to exotics. However, in some of the very few previously reported trials with tropical trees in unsterile soils, mycorrhizal inoculation failed to improve tree seedling growth (Cuenca *et al*., 1990). Inoculating with selected AMF did not affect collar girth, root weight and root length of sandal seedlings (Binu *et al*., 2015).

2.5. STANDIZATION OF INOCULATION DOSAGE

When the alginate inoculum was used with the highest doses, mycorrhizal development was very rapid, which proves that the number of fungal propagules in each bead is an important factor in the efficiency of the inoculums (Mortier *et al*., 1988). A positive dose response relationship is generally attributed to a better colonization of the rhizosphere by the introduced microorganism (Raaijmakers *et al*., 1995), leading to a larger population which produces more of the effective substances either directly, because the cells are more numerous, or indirectly through quorum-sensing mechanisms within high-density micro-colonies (Chin-A-Woeng *et al*., 1997) increasing the inoculation dose generally increases plant protection (Bull *et al*., 1991; Raaijmakers *et al*., 1995). Some detrimental effects on root growth were also observed with high inoculation doses (Kapulnik *et al*., 1985; Bashan, 1986). A negative response was in bacterial inoculation in different doses, the lowest doses were the most efficient ones (Klett *et al*., 1999).

To standardize the critical level of AMF for *Prosopis cineraria* seedling, *Glomus* sp. was used at different spore levels (0, 100, 200, 300, 400, 500, 600, 700,800 and 900 g germinanable spores per seedling per polybag). Mycorrhizal inoculation increased plant height, dry matter yield, root length and per cent root infection. Eighty five per cent infections were found to be sufficient for optimum response by *P.*

cineraria seedling. The critical level of spores was found to be 400 per polybag (1 kg soil) for *P. cineraria* seedling (Verma *et al*., 2009). The standardization of inoculum dose in *Tecomella undulata* seedlings was found that inoculum levels play an important role in growth. 100 g rhizosphere soil (500 germinanable spores) of AMF found to be the best dose for better growth (Srivastava *et al*., 2004). Crops for transplantation can be pre-inoculated with AMF in the nursery itself so that the inoculum quantity can be reduced. In chilli among different dose recorded maximum colonization and the economical dose for satisfactory colonization was found to be 850 g m^{-2} (Kavitha *et al*., 2004).

2.6. INFLUENCE OF AMF ON TREE SEEDLING PHYSIOLOGY

The high percentage of root colonization in AM fungal treated plants is directly correlated with a better nutrient uptake, increased total chlorophyll content, an increase in the rate of photosynthesis and transpiration (Eissenstat *et al*., 1993; Peng *et al*., 1993; Mathur and Vyas, 1995; Rajasekaran and Nagarajan, 2005), and thereby improved root and shoot growth were expected (Thaker and Fasrai, 2002; Farshian *et al*., 2007). These results are also in conformity with (Azam and Jalil, 2007; Dutt *et al*., 2013) who also reported an increase of total chlorophylls when inoculated with AMF. The AMF plants had a comparatively low transpiration rate and higher water use efficiency (WUE) as compared with non mycorrhizal plants. This reduced transpiration rate was due to increased stomatal resistance provided by the AMF colonization by decreasing stomatal conductance (Mathur and Vyas, 1995). Abbaspour *et al*., (2012) suggest controversies to above that mycorrhiza could increase the rate of leaf transpiration, reduce leaf temperature and restrain the decomposition of chlorophyll.

Similarly, inoculation with all the three AMF (*G. occultum, G. mosseae* and *G. aggregatum*), resulted in significant increase in chlorophyll content of *Acacia mangium* compared to the control plants (Ghosh and Verma, 2006). Mycorrhizal inoculation (*G. mosseae* and *S. calospora*) significantly reduced 31 per cent photosynthetic rate in *Azadirachta excels* seedlings (Huat et al., 2002). The presence of AMF on root system of plants is correlated with higher rates of net photosynthesis (Reid et al., 1983; Nylund and Unestam, 1987). The difference in photosynthetic rate could probably be due to

excessive starch accumulation in leaves of seedlings inoculated with AMF. Maximum photosynthetic rates in the *Dalbergia sissoo* were observed in AMF inoculated plants, an effect corroborated by increased root biomass (Bisht et al., 2009). Since mycorrhizal infection often results in increased allocation of C to the root system, it implies increased root biomass, increased root respiration and mycelial biomass which could explore a larger soil volume for nutrient, consequently resulting in higher uptake rates (Jakobsen 1995). The transpiration rates for plants inoculated with AMF were higher, which could also explain higher nutrient content in the shoots of plants grown in these soils. Changes in transpiration could cause a change in the rate of photosynthesis changing the supply of carbohydrate to the fungus. Alternatively, higher nutrient uptake due to higher transpiration rates could be due to mass flow of nutrients towards the root (Sharma *et al.* 1991).

2.7. FACTORS INFLUENCING THE EFFICIENCY OF AM FUNGI

Establishment of symbiosis involves a range of factors which can impact on the AMF association, both directly, by damaging or killing AMF and indirectly, by creating conditions either favorable or unfavorable to AMF. In general, it is an interaction of host, fungi and soil factors.

2.7.1. Abiotic factors

The soil factors therefore exert maximum influence on AMF. In light textured soil spore count is more, but survival percentage was generally more in loamy soils than in sandy soils. The pH optimum of spore germination would probably differ with each AMF species and the environment to which each is indigenous (Green *et al*., 1976). Gerdemann and Trappe, (1974) observed that *G. mosseae* common in alkaline flatland soils germinated well on water or soil extract gar at pH 6 to 9. Thus, it appears that pH can influence the germination of AMF spores, but germination seems to occur within a range is still acceptable for plant growth and AMF species have distinct behaviours at different levels of pH (Graw, 1979). Below field capacity, germination declined with no germination (Daniels and Trappe, 1980). Higher levels of germination could eventually be obtained at low water potential, if spores were incubated longer. He further observed that germ tube length was reduced at low water potential (Koske, 1981). Furlan and

Fortin (1973) and Hayman (1974) reported that higher temperatures generally resulted in greater root colonization and increased sporulation. Mikanova *et al*., (2001) determined the effect of heavy metal pollutants (Cd, Pb, Zn and As) on the soil microflora and their activities. Increased heavy metal content in the soil resulted in a decreased AMF colonization percentage. Much of the influence of soil fertility on root colonization is plant mediated and the root colonization is inhibited at high phosphorus levels because of the decreased root exudation (Menge *et al*., 1978). The increased light intensity increased percentage colonization (Ferugson, 1981) noticed that day lengths also increased root colonisation. Ferguson (1981) observed that low light intensity can significantly reduce root colonization, but its effect on sporulation may be less pronounced. Seasonal variation in percent root colonization with AMF and the lowest colonization was during winter and highest during last summer and autumn (Mago and Mukerji, 1994).

2.7.2. Biotic factors

In addition to abiotic factors the biotic factors like host, genotypic variation among the host, cropping sequence, rhizosphere effect and root exudates exert an equal influence in determining the AMF population in soil. In addition to host factors the soil microflora also influences the AMF population in soil. Certain AMF species may be efficient in stimulating the growth of certain plant species, but each AMF is generally able to colonize every AMF host species (Mosse, 1973). It appeared that the host plant could affect sporulation and possibly survival of AMF. All these workers point out the necessity of taking into consideration the existence of AMF symbiosis in the selection processes, since greater yields at lowest cost can only be obtained when better fitness of plant species or varieties to this association is exploited. The presence of plant roots causes a rapid and intense stimulation of the microbial population in the rhizosphere region and AMF symbiosis was initiated at the zone of elongation from where root exudation was greatest (Smith and Walker, 1981).

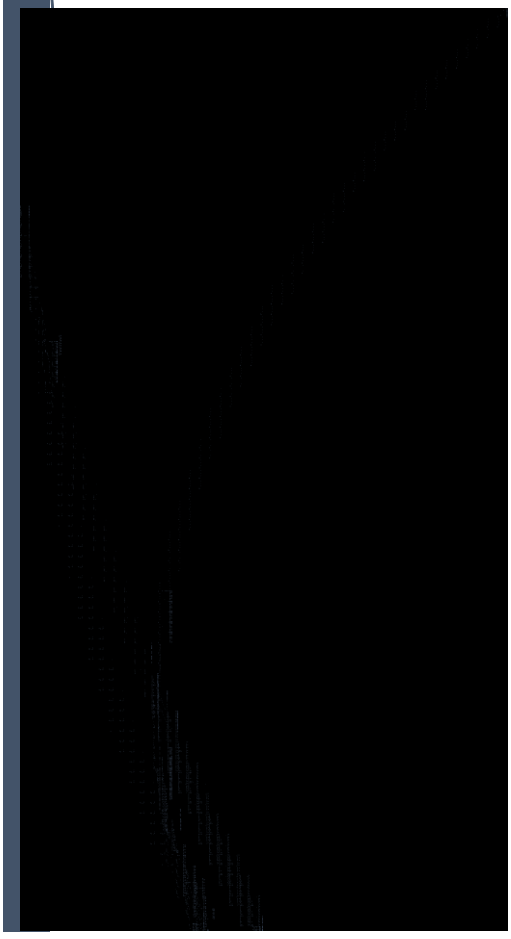
2.7.3. Negative effect of AMF

Though the AMF association can offer multiple benefits to the host plant it may not be obviously mutualistic at all points in time, and it is possible under some

conditions that the AMF may cheat their host plant into supplying C with no apparent benefit to the plant. In some cases, this can cause a decline in growth (Lerat *et al*., 2003). However, proving that AMF are actually cheating is difficult (Fitter, 2001) not least because of the wide range of benefits to the host, which may only become obvious at specific times or under certain environmental conditions or stresses.

Perusal of the literature indicated that studies on screening of AMF for different levels in tree species were scanty. Investigation regarding effect of AMF on different levels in teak and mahogany seedlings is not available. Hence, the present study leads to levels of selected native AMF inoculation based on the growth, physiology and quality of seedlings.

MATERIALS AND METHODS



3. MATERIALS AND METHODS

The present investigation on "Harnessing arbuscular mycorrhizal fungi (AMF) for quality seedling stock production of *Tectona grandis* Linn. and *Swietenia macrophylla* King." was conducted at the College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala during the period 2013 to 2015.

3.1. STUDY SITE

The study was conducted at COF, KAU, Vellanikara 40 m above mean sea level 10°32' 52.05" N latitude and 76°26' 45.55" E longitude. The area experiences a warm and humid climate with distinct rainy season. The soils and subsoils are porous and extremely well drained. The area received a total rainfall of <3000 mm during 2014. The weather parameters of the study area during 2014 were collected from Agrometeorological Observatory in the KAU campus given in Fig. 1.

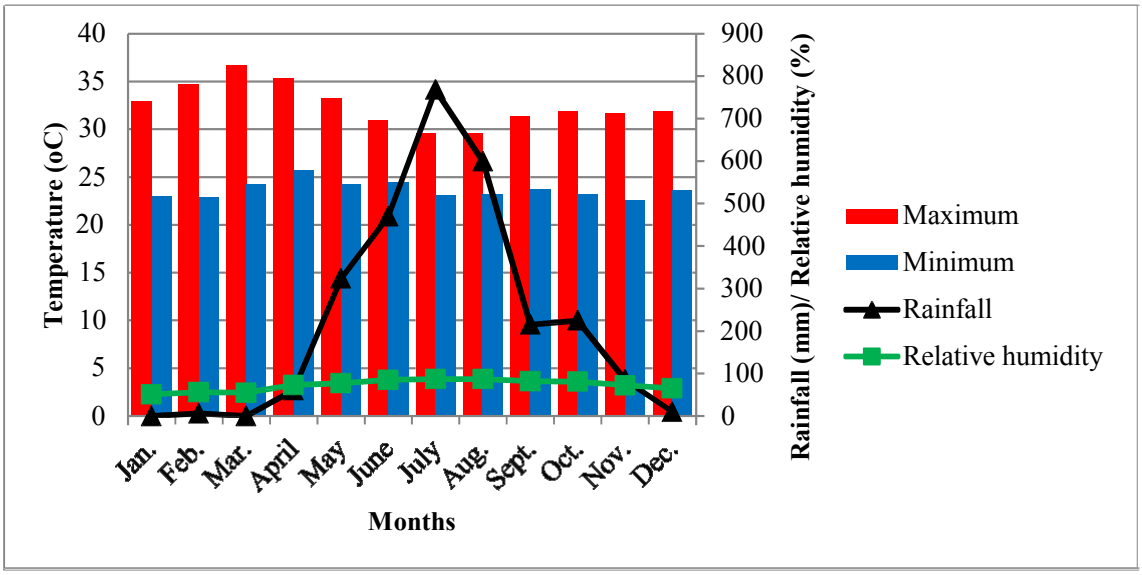


Fig.1. Weather parameters of study area during 2014

3.2. METHODOLOGY

The experiment was conducted to investigate the influence of AMF for the quality seedling production of the following tree species

1. Teak (*Tectona grandis* Linn.)
2. Mahogany (*Sweitenia macrophylla* King.)

3.3. Seedling preparation

3.3.1. Seed collection

Seeds were used to raise seedlings. Teak seeds were collected from three different plantations of Nilambur Forest Division (10^{o} 15' and 10^{o}26' North latitudes and 75^{o} 46' and 76^{o} 33' East longitudes) in Malappuram district of Kerala. The soil type was fine loam. The mature mahogany seeds were collected from the trees standing near the tree nursery building of College of Forestry.

3.3.2. Seed pre-treatment

The large sized fruit of teak (above 9 mm) were used for the production of quality seedlings (Jijeesh and Sudhakara., 2013). The seeds were pretreated by alternate wetting and drying for seven days (Bedell, 1989). The pretreated seeds were sown in beds (1.2 x 12.2 m). Mature mahogany pods were collected and kept in shade for after-ripening. The seeds were dewinged and treated with 100 ppm benzyl adenine (BA) for 12 hrs (Vidyasagaran *et al*., 2014). The pretreated seeds were sown in nursery beds (1.2 x 12.2 m).

3.3.2. Planting of germinates and after care

The seedlings (30 days old) were transplanted in polythene bags (12 cm l x 16 cm w, gauge 75 micron) containing 1:1 homogenous mixture of soil and sand. These seedlings were arranged in three blocks which contains 30 seedlings were grown in open condition throughout the experimental period and watered regularly.

3.4. MYCORRHIZAL APPLICATION

3.4.1. Mycorrhizal inoculums collection

Pure cultures of *Funneliformis mosseae* (T.H. Nicolson & Gerd.) C. Walker & Schuessler 2010, *Glomus intraradices* (N.C. Schenck & G.S. Sm.) C. Walker & Schuessler (2010) and *Glomus proliferum* (Dalpé & Declerck) C. Walker & Schuessler (2010) native species vermi-paste based (1000 spores in 100 g) were obtained from TERI (The Energy Research Institute, New Delhi) and stored in refrigerate condition.

3.4.2. Mass multiplication of AMF

The 0.5 mm sieved soil and sand mixture (1:1) was fumigated using 0.5 per cent formaldehyde for 20 days. After the completion of the process, to remove the chemical content the soil was kept in open and mixed repeatedly to remove the formaldehyde residues. Grow bags having a capacity of 5 kg were filled with fumigated soil. To the grow bag, 10 g AMF (vermi-paste and AMF 80 germinable spores) was mixed and five sterilized (0.01 per cent sodium hypochloride for 10 min and washed in sterile water) maize seeds were sown. The plants were irrigated daily using the sterile water. Every 10 days interval, the grow bags were applied with Hoagland's solution (Hoagland and Arnon, 1950) @ 50 ml per plant. The maize roots were checked for colonization per cent frequently (Philips and Hayman, 1970). The shoot portion of the maize was removed when the root colonization was more than 80 % and the soil containing of roots were thoroughly mixed to obtain inoculum.

3.4.3. Inoculation of AMF in different treatments

The experiment was laid as a Factorial Randomized Block Design with three factors. Tree species (Teak and Mahogany) formed the first factor while, AMF species (*F. mosseae, G. intradices* and *G. proliferum*) formed the second factor and levels of AMF (10, 25 and 50 g) formed the third factor. The experiment was replicated three times and each experimental unit comprised of 40 seedlings. The treatments were randomised using lot method. A gap (1 m) was given between each block. Observations were taken one month after inoculation of AMF along with control.

T1 - *F. mosseae* with 10 g inoclum

T2 - *F. mosseae* with 25 g inoclum

T3 - *F. mosseae* with 50 g inoclum

T4 - *G. intradices* with 10 g inoclum

T5 - *G. intradices* with 25 g inoclum

T6 - *G. intradices* with 50 g inoclum

T7 - *G. proliferum* with 10 g inoclum

T8 - *G. proliferum* with 25 g inoclum

T9 - *G. proliferum* with 50 g inoclum

T10 - Without AMF inoculation (Control)

Plate 1. Solarized potting media (soil and sand mixture in 1:1)

Plate 2. Mass multiplication of AMF in “Grow bags” with maize as the host

The AMF inoculum was inoculated at the time of transplanting @ 10 spores /g.

3.5. OBSERVATIONS

3.5.1. Above-ground parameters

Three seedlings selected at random from each replication were tagged to record the following growth observations at 30, 60, 90, 120, 150 DAI (Days after inoculation) of AMF.

3.5.1.1. Shoot height

The height of the seedlings was measured from collar to the terminal bud with a meter scale and expressed in centimeters.

3.5.1.2. Collar diameter

The collar diameter of the seedlings were measured along two diametrically opposite directions of the seedlings using vernier calipers (having least count = 0.02 mm) and expressed in millimeters.

3.5.1.3. Number of leaves

Number of leaves retained and functional leaves (fully opened) were counted and recorded.

3.5.1.4. Leaf area

The leaves collected from different treatments were immediately used to measuring the leaf area. It was using a leaf area meter (Model LI 3100 LI-Cor, Nebraska, USA) and expressed in cm^2.

3.5.1.5. Fresh weight of shoot

Three seedlings were selected randomly from each treatment at monthly intervals. The fresh weights of shoots were recorded using electronic balance and expressed in gram.

3.5.1.6. Dry weight of shoots

After measuring fresh weight, the shoot portion of the seedlings was dried in hot air oven at a temperature of 60ºC ± 2ºC for 48 hours. The dry weight also was recorded using an electronic balance and expressed in gram.

3.5.1.7. Fresh weight of leaves

Three seedlings were selected randomly from each treatment at monthly intervals. The fresh weight of leaves was recorded using electronic balance and expressed in gram.

3.5.1.8. Dry weight of leaves

After measuring fresh weight, the leaves portion of the seedlings was dried in hot air oven at a temperature of 60ºC ± 2ºC for about 48 hours. The dry weight also was recorded using an electronic balance and expressed in gram.

3.5.2. Below-ground parameters

The seedlings selected for the above-ground observations were also used for the below ground observations. After plucking the leaves for leaf area determination, the seedlings were taken out with root system intact, washed thoroughly in running tap water and dried.

3.5.2.1. ***Tap root length***

The length of the tap root was recorded in centimeters from collar to the tip of it.

3.5.2.2. ***Number of lateral roots***

Number of lateral roots produced by individual seedlings was recorded.

3.5.2.3. ***Fresh weight of roots***

The fresh weight of roots was recorded using electronic balance and expressed in gram.

3.5.2.4. ***Dry weight of roots***

The root portion of the seedlings was dried in hot air oven at a temperature of 60ºC ± 2ºC for about 48 hours.

3.5.2.5. ***Total fresh weight***

Total fresh weight of the seedling was worked out at monthly intervals by adding the fresh weight of shoot, leaves and roots and expressed in grams.

3.5.2.6. *Total dry weight*

Total dry weight was worked at monthly intervals by adding the dry weight of shoot, leaves and roots and expressed in grams.

3.5.2.7. *Shoot-root length ratio*

Shoot-root length ratio was worked out at monthly intervals using the formula

$$\text{Shoot} - \text{root length ratio} = \frac{\text{Shoot length (cm)}}{\text{Root length (cm)}}$$

3.5.2.8. *Shoot-root biomass ratio*

Shoot-root biomass ratio was worked out at monthly intervals using the formula

$$\text{Shoot} - \text{root biomass ratio} = \frac{\text{Shoot weight (g)}}{\text{Root weight(g)}}$$

3.5.2.9. *Vigour Index I*

The vigour index (VI) of the seedlings was calculated using the formula (Kharb *et al*., 1994).

$$\text{Vigour Index I} = \frac{\text{Germination Percentage x (Shoot length} + \text{total seedling length)}}{100}$$

3.5.2.10. *Vigour Index II*

The vigour index (VI II) of the seedlings was calculated using the formula (Kharb *et al*., 1994).

$$\text{Vigour Index II} = \frac{\text{Germination Percentage x Seedling dry weight}}{100}$$

3.5.3. Physiological observations

Growth analysis is used to account for growth in terms of functional or structural significance. The types of growth analysis require measurement of plant biomass and assimilatory area (leaf area) and methods of computing certain parameters that describe growth. Plant physiological responses of seedlings belonging to each treatment sampled at 150 DAI.

3.5.3.1. Leaf Area Ratio

The term, Leaf Area Ratio (LAR) was suggested by Radford (1967), expresses the ratio between the area of leaf lamina to the total plant biomass or the LAR reflects the

leafiness of a plant or amount of leaf area formed per unit of biomass and expressed in $cm^2\ g^{-1}$ of plant dry weight.

$$\text{Leaf Area Ratio} = \frac{\text{Leaf area per plant}}{\text{Plant dry weight}}$$

3.5.2.2. ***Leaf Weight Ratio***

Leaf weight ratio is expressed as the dry weight of leaves to whole plant dry weight (Kvet *et al.,* 1971).

$$\text{Leaf Weight Ratio} = \frac{\text{Leaf dry weight}}{\text{Plant dry weight}}$$

3.5.2.3. ***Specific Leaf Area***

Specific leaf area is a measure of the leaf area of the plant to leaf dry weight and expressed in cm^2g^{-1} (Kvet *et al.,* 1971).

$$\text{Specific Leaf Area} = \frac{\text{Leaf area}}{\text{Leaf weight}}$$

3.5.2.4. ***Specific Leaf Weight***

It is a measure of leaf weight per unit leaf area. Hence, it is a ratio expressed as g cm^{-2} (Pearce *et al.,* 1968).

$$\text{Specific Leaf Weight} = \frac{\text{Leaf weight}}{\text{Leaf area}}$$

3.5.2.5. ***Absolute Growth Rate***

Absolute Growth Rate is the total gain in height by a plant within a specific time interval. It is generally expressed as cm/day.

$$\text{Absolute Growth Rate} = \frac{(h_2 - h_1)}{t_2 - t_1}$$

Where,

h_1-Plant height at time (t_1)

h_2-Plant height at time (t_2)

3.5.2.6. ***Relative Growth Rate***

Relative Growth Rate (RGR) expresses the total plant dry weight increase in a time interval in relation to the initial weight or Dry matter increment per unit biomass

per unit time or grams of dry weight increase per gram of dry weight and expressed as unit dry weight / unit dry weight / unit time (g $g^{-1}day^{-1}$) (Williams, 1946).

$$\text{Relative Growth Rate} = \frac{(\log_e W_2 - \log_e W_1)}{t_2 - t_1}$$

Where,

W_1-Whole plant dry weight at time (t_1)

W_2-Whole plant dry weight at time (t_2)

3.5.2.7. ***Net Assimilation Rate***

NAR is defined as dry matter increment per unit leaf area or per unit leaf dry weight per unit of time (Williams, 1946). The NAR is a measure of the average photosynthetic efficiency of leaves in a crop community. NAR is expressed as the grams of dry weight increase per unit dry weight or area per unit time (g $g^{-1}day^{-1}$).

$$\text{Net Assimilation Rate} = \frac{(W_2 - W_1)}{(t_2 - t_1)} \times \frac{(\log_e L_2 - \log_e L_1)}{(L_2 - L_1)}$$

Where,

$W_1$and W_2 is dry weight of whole plant at time t_1 and t_2 respectively

L_1 and L_2 are leaf weights or leaf area at t_1 and t_2 respectively

t_1 – t_2 are time interval in days

3.5.2.8. ***Chlorophyll content***

In order to find the effect of AMF inoculation in chlorophyll content at monthly intervals, the chlorophyll content of the seedlings was measured using chlorophyll meter (SPAD-502, Minolta) from selected three mature leaves from the second whorl.

3.5.2.9. ***Photosynthetic rate***

The photosynthetic rates of different treatments were recorded using infra-red gas analyzer (IRGA) model ADC BioScientific LCpro-SD System Serial No.33669 at 869 lux and the amount of CO_2 expressed in µmol m^{-2} s^{-1}.

3.5.2.10. ***Transpiration rate***

The transpiration rates of seedlings belonging to different treatments were recorded using Infra-red gas analyzer (IRGA) model ADC BioScientific LCpro-SD System Serial No.33669 at 869 lux and the amount of H_2O expressed in µmol m^{-2} s^{-1}.

3.5.2.11. ***Plant water potential***

The water potential of the seedlings belonging to different treatments was measured with the aid of plant water status console (Scholander *et al*., 1965). The pre-drawn water potential was recorded by cutting leaf from the plant with a sharp blade and taking immediate reading in the instrument. The readings were taken as soon as the leaves were collected in order to avoid errors due to water loss through the cut ends. Water potential was expressed in 'MPa'.

3.5.2.12. ***Leaf temperature***

The leaf temperature of the seedlings belonging to different treatments was recorded using a thermocouple attached to the IRGA and expressed in ^{o}C.

3.5.2.13. ***Stomatal conductance***

The Stomatal resistance of the seedlings belonging to different treatments was recorded using a Infra-red gas analyzer (IRGA) model ADC BioScientific LCpro-SD System Serial No.33669 at 869 lux and expressed in s cm^{-1}.

3.5.2.14. ***Relative water content***

In order to estimate the relative water content a small portion of leaf was cut and put kept in water for 3 hours. Leaf samples were dried using a blotting paper and turgid weight was measured. These samples were then dried in hot air oven set a temperature of 120 ^{0}C for two days and dry weight was taken. The RWC was calculated based on the formula

$$\text{Relative Water Content} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \text{x100}$$

3.5.3. Per cent of AMF association

Three seedlings belonging to each treatment were destructively sampled at 150 DAI. The fine root samples were collected from soil.

3.5.3.1. ***Root colonization per cent***

The per cent AMF colonization in the roots of different treatments at 150 DAI was determined (Philips and Hayman, 1970). The root samples were cleaned and cut into one centimeter bits and fixed in FAA (Formaldehyde: Acetic acid: Alcohol in 5:5:90 proportion) for 24 hrs. The roots were then autoclaved with 10 per cent KOH

Plate 3. Estimation of chlorophyll content using SPAD meter

Plate 4. Estimation of photosynthetic rate and transpiration rate using IRGA

solution at 1.06 kg cm^{-2} for 15 minutes. The alkalinity of the samples was then neutralized with two per cent hydrochloric acid. Staining was done using 0.05 per cent trypan blue solution in lacto phenol reagent (lactic acid-20 ml, phenol-20 ml, glycerol-40 ml and distilled water-40 ml) for 12 hrs and arranged on a clean slide covered with cover slips. Scanned under compound microscope for the presence of mycelium, vesicles and arbuscules. The AMF colonisation per cent was calculated from the formula.

$$\text{AMF colonization per cent} = \frac{\text{Number of roots bits of positive for AMF colonization}}{\text{Total number of root bits observed}} \text{x}100$$

3.5.2.2. ***Total spore count***

The extrametrical chlamydospores produced by the AMF were estimated following the wet sieving and decanting technique (Gerdemann and Nicolson, 1963). Twenty five grams of the substrate was collected from each poly bag and made into a uniform suspension in 250 ml water by thoroughly stirring it. The suspension was then passed through a series of sieves ranging from 600, 300, 212, 150, 106 and 45 µm kept one below the other in same order. The contents of the bottom two sieves were made into a suspension in water and transferred to a nylon mesh (45 µm) placed in Petri dish separately. The Petri dish containing the nylon mesh with the spores was observed under stereo microscope and the total AMF spore count was estimated and expressed per gram of inoculum.

3.5.4. Quality assessment of seedlings

The biometric observations obtained from the seedlings at 30, 60, 90, 120 and 150 DAI, the following seedling quality indices were calculated.

3.5.4.1. ***Quality index***

Quality index which is a measure to assess the quality of seedling based on the height, stem diameter and dry biomass was calculated using the following formula (Hatchell, 1985).

$$\text{Quality index} = \frac{\text{Seedling dry biomass (g)}}{\frac{\text{Height (cm)}}{\text{Diameter(mm)}} + \text{Top dry biomass (g)}}$$

Plate 5. Estimation of root colonization per cent

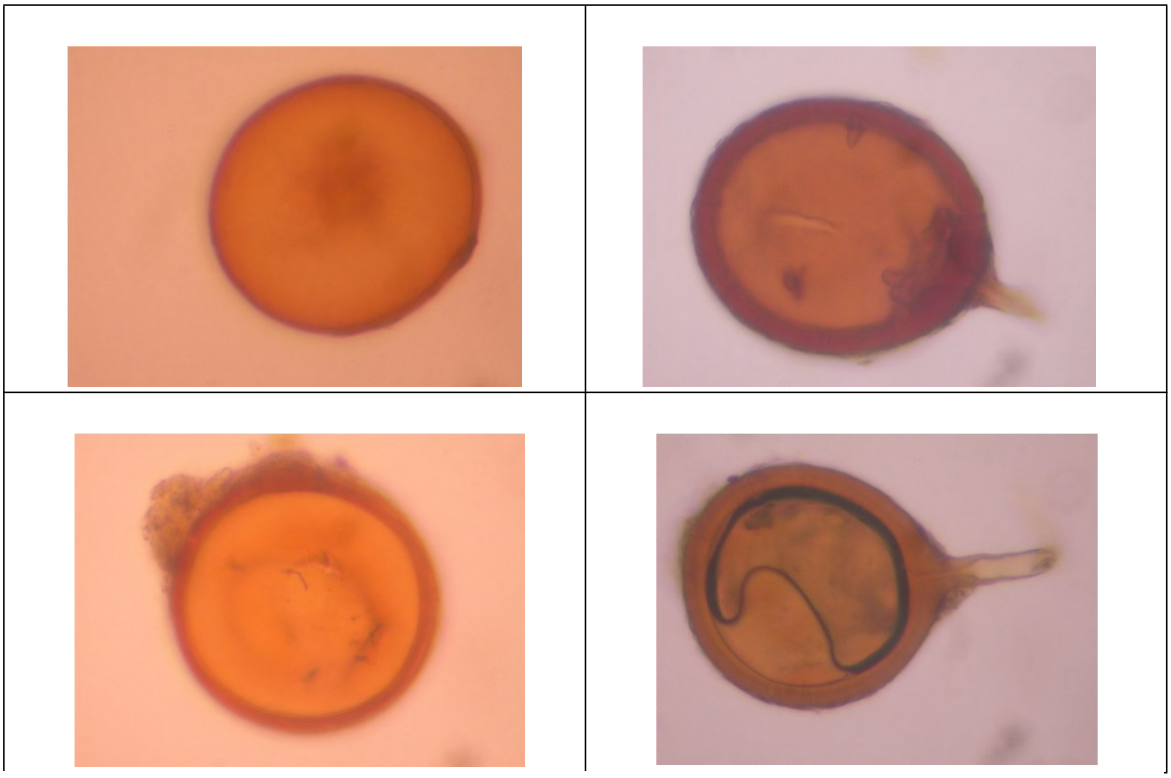


Plate 6. AMF spores from spore count with stereo microscope

3.5.2.2. *Biovolume index*

Biovolume index, which is a non-destructive quick method to calculate the above-ground portion of the tree seedlings, was calculated using the formula suggested by Hatchell (1985).

$$\text{Biovolume index} = \text{Plant height (cm)} \times \text{Stem diameter (mm)}$$

3.5.2.3. *Mycorrhizal Efficiency Index*

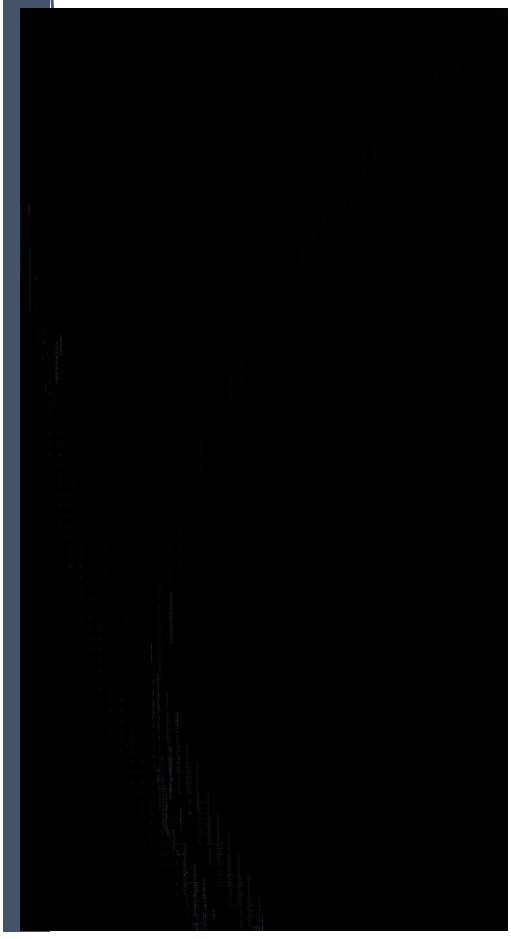
Mycorrhizal Efficiency Index (MEI) or Mycorrhizal Dependency allows assessment of the growth improvement by mycorrhizal fungus (Secilia and Bagyaraj, 1994).

$$\text{Mycorrhizal Use Efficiency index (MUE)} = \frac{\text{Dry matter of inoculated plant} - \text{Dry matter of non inoculum plant}}{\text{Dry matter of inoculated plant}} \times 100$$

3.6. STATISTICAL ANALYSIS

The final data was subjected to one-way Analysis of Variance (ANOVA). Based on the outcome of ANOVA on all data, post-hoc analysis had been performed in the form of Duncan's Multiple Range test (Duncan, 1955) to separate the means. Cluster analysis was carried out taking shoot height, collar diameter, tap root length, total dry weight, Relative Growth Rate, Chlorophyll content, photosynthetic rate, biovolume index, quality index and MEI as characters to find the best treatment.

RESULTS



4. RESULTS

The results obtained on the effect of Arbuscular Mycorrhizal Fungi (AMF) for quality seedling stock production of *Tectona grandis* and *Swietenia macrophylla* are described in the following chapter.

4.1. TEAK (*Tectona grandis)*

4.1.1. **Above-ground parameters**

4.1.1.1. Shoot height

Analysis of variance revealed significant difference in seedling height due to different treatments over time. In general, seedling height at monthly intervals showed an increasing trend (Table 1). Data pertaining to 30 DAI seedling heights, there was no significant variation in seedling height due to various treatments. At 60 DAI, all except T1, T4 and control (T10) were on par. The highest (14.2 cm) seedling height was observed in *F. mosseae* with 10 g inoculum (T1) and least (9.6 cm) for *G. intradices* with 10 g inoculum (T4). At 90 DAI, treatments T1, T2, T5, T6 and T7 were on par. The highest (15.2 cm) seedling height was observed in *G. proliferum* with 25 g inoculum (T8) and least (12.0 cm) for *G. intradices* with 10 g inoculum (T4). At 120 DAI, all except treatments T8 and T9 were on par. The highest (57.2 cm) seedling height was observed in *G. proliferum* with 50 g inoculum (T9) and least (12.3 cm) for *G. intradices* with 10 g inoculum (T4). At the end of the study follow the same pattern of previous month, treatments T3, T5 and T6 were on par. With regard to seedling height, the highest value was (60.8 cm) recorded for *G. proliferum* with 50 g inoculum (T9). Data pertaining to next lower and comparable height growth was observed in seedlings subjected to *G. proliferum* with 25 g inoculum (T8) (45.9 cm). The least (14.2 cm) seedling height occurred in seedlings subjected to *F. mosseae* with 25 g inoculum (T2). Greater than fourfold increase seedling height was observed in seedlings subjected to *G. proliferum* with 50 g inoculum compared to control.

Table 1. Seedling height (cm) of *Tectona grandis* as influenced by different treatments at monthly intervals

Seedling height (cm)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	10.5	14.2^{a}	14.4^{abc}	16.6^{c}	19.9^{c}
T2	11.0	12.8^{ab}	13.7^{abc}	13.3^{c}	14.2^{d}
T3	9.8	11.0^{ab}	12.2^{c}	12.8^{c}	16.4^{cd}
T4	9.3	9.6^{b}	12.0^{c}	12.3^{c}	14.9^{d}
T5	11.4	11.6^{ab}	13.9^{abc}	14.2^{c}	17.8^{cd}
T6	13.7	13.2^{ab}	13.1^{abc}	12.5^{c}	16.1^{cd}
T7	11.2	12.0^{ab}	13.9^{abc}	16.9^{c}	20.5^{c}
T8	11.9	12.2^{ab}	15.2^{a}	42.5^{b}	45.9^{b}
T9	10.2	11.0^{ab}	14.9^{ab}	57.2^{a}	60.8^{a}
T10	10.6	11.65^{b}	12.4^{bc}	12.5^{c}	14.5^{d}
SEm±	0.41^{ns}	0.37*	0.32*	2.84*	2.83*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.1.2. Collar diameter

Analysis of variance revealed significant difference in seedling collar diameter due to different treatments over time. Seedling collar diameter at monthly intervals showed an increasing trend (Table 2). Data pertaining to 30 DAI seedling collar diameters, treatments T2 and T5 were on par. The highest value (2.46 mm) was recorded for seedlings treated with *G. intradices* with 50 g inoculum (T6) and least (0.81 mm) for control (T10). At 60 DAI, there was no significant variation in seedling collar diameter due to various treatments. At 90 DAI, treatments T1, T2 and T6 were on par. The highest (4.91 mm) collar diameter was observed in *G. proliferum* with 25 g inoculum (T8) and least (3.10 mm) for *F. mosseae* with 50 g inoculum (T3). At 120 DAI, treatments T2, T3, T4 and T6 were on with other treatments. The highest (12.18 mm) collar diameter was observed in *G. proliferum* with 50 g inoculum (T9) and least (3.54 mm) for *F. mosseae* with 50 g inoculum (T3). At the end of the study, except T2, T3, T4 and T6 were on par. With regard to seedling collar diameter, the highest value was (13.42 mm) recorded for *G. proliferum* with 50 g inoculum (T9) and least (4.78) seedling collar diameter occurred in seedlings treated with *F. mosseae* with 50 g inoculum (T3) at the end of the study.

Table 2. Collar diameter (mm) of *Tectona grandis* as influenced by different treatments at monthly intervals

Collar diameter (mm)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	2.00^{abc}	2.58	3.43^{bc}	5.75^{bc}	6.99^{cd}
T2	1.60^{bcd}	2.07	3.45^{bc}	3.63^{d}	4.87^{e}
T3	2.16^{ab}	2.35	3.10^{c}	3.54^{d}	4.78^{e}
T4	1.07^{de}	2.20	3.27^{c}	3.77^{d}	5.01^{e}
T5	1.63^{bcd}	1.99	4.27^{ab}	4.50^{cd}	5.74^{de}
T6	2.46^{a}	2.39	3.46^{bc}	3.71^{d}	4.95^{e}
T7	1.41^{cde}	2.21	4.46^{a}	6.01^{b}	7.25^{c}
T8	1.84^{abc}	2.00	4.91^{a}	9.24^{a}	10.48^{b}
T9	0.94^{de}	2.13	4.59^{a}	12.18^{a}	13.42^{a}
T10	0.81^{e}	1.67	4.31^{ab}	3.94^{d}	5.18^{e}
SEm±	0.11*	0.12^{ns}	0.14*	0.53*	0.53*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.1.3. Number of leaves

Analysis of variance revealed significant difference in number of leaves due to different treatments over time. While, seedling number of leaves at monthly intervals showed an increasing trend (Table 3). Data pertaining to 30 DAI seedling number of leaves, all except T2, T5 and control (T10) were on par with other treatments. The highest value (9.33) was recorded for seedlings treated with *F. mosseae* with 25 g inoculum (T2) and least (6.3) for *G. intradices* with 25 g inoculum (T5) and control (T10). At 60 DAI, there was no significant variation in number of leaves due to various treatments. At 90 DAI, treatments T2, T4 and T9 were on par. The highest (10.3) number of leaves was observed in *G. intradices* with 25 g inoculum (T5) and least (5.3) for *F. mosseae* with 10 g inoculum (T1). At 120 DAI, treatments T3, T4, T5 and T6 were on par. The highest (10.67) number of leaves was observed in *G. proliferum* with 50 g inoculum (T9) and least (4.3) for control (T10). At the end of the study, treatments T3, T4, T5 and T6 were on par. With regard to seedling number of leaves, the highest value was (14.7) recorded for *G. proliferum* with 50 g inoculum (T9). Data pertaining to next lower and comparable height growth was observed in seedlings subjected to *G. proliferum* with 25 g inoculum (T8) (10.0) and least (6.3) occurred in seedlings kept as control without treatments (T10) at the end of the study.

Table 3. Number of leaves of *Tectona grandis* as influenced by different treatments at monthly intervals

Number of leaves					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	7.0^{ab}	7.3	5.3^{c}	8.3^{ab}	10.7^{b}
T2	9.3^{a}	8.3	7.3^{abc}	7.7^{abc}	9.7^{b}
T3	7.0^{ab}	7.0	9.7^{ab}	6.0^{bcd}	8.7^{bc}
T4	8.0^{ab}	8.0	8.7^{abc}	6.7^{bcd}	8.7^{bc}
T5	6.3^{b}	7.0	10.3^{a}	6.0^{bcd}	8.0^{bc}
T6	8.3^{ab}	9.0	9.7^{ab}	5.7^{bcd}	7.7^{bc}
T7	7.3^{ab}	8.0	6.7^{bc}	4.7^{cd}	6.7^{c}
T8	8.3^{ab}	9.0	7.7^{abc}	8.3^{ab}	10.0^{ab}
T9	7.0^{ab}	7.7	9.3^{ab}	10.7^{a}	13.3^{a}
T10	6.3^{b}	10.00	6.3^{bc}	4.3^{d}	6.3^{c}
SEm±	0.27*	0.39^{ns}	0.40*	0.42*	0.44*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.1.4. Leaf area

Analysis of variance revealed significant difference in leaf area per plant due to different treatments over time. In general, leaf area per plant at monthly intervals showed an increasing trend (Table 4). Data pertaining to 30 DAI leaf area per plants, all except T6 and control (T10) were on par. The highest value (38.38 cm^2) was recorded for seedlings treated with *G. intradices* with 50 g inoculum (T6) and least (7.45 cm^2) for control (T10). At 60 DAI, there was no significant variation in leaf surface area per plant due to various treatments. At 90 DAI, all except T5, T7, T8, T9 and control (T10) were on par with other treatments. The highest (225.03 cm^2) leaf surface area per plant was observed in *G. proliferum* with 50 g inoculum (T9) and least (20.90 cm^2) for *F. mosseae* with 50 g inoculum (T3). At 120 DAI, all except T1, T5, T7, T8 and T9 were on par. The highest (3108.48 cm^2) leaf surface area per plant was observed in *G. proliferum* with 50 g inoculum (T9) and least (31.77 cm^2) for control (T0). At the end of the study follow the similar trend, With regard to leaf area per plant, all except T1, T5, T7, T8 and T9 were on par. The highest value was (3167.48 cm^2) recorded for *G. proliferum* with 50 g inoculum (T9) and least leaf area per plant (61.96 cm^2) occurred in seedlings without AMF inoculation kept as control (T10) at the end of the study.

Table 4. Leaf area per plant (cm^2) of *Tectona grandis* as influenced by different treatments at monthly intervals

Leaf area per plant (cm^2)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	24.92^{ab}	28.66	26.12^{d}	329.80^{c}	353.80^{c}
T2	12.87^{ab}	17.87	23.52^{d}	59.80^{d}	83.80^{d}
T3	28.66^{ab}	19.00	20.90^{d}	37.96^{d}	61.96^{d}
T4	12.21^{ab}	26.48	25.23^{d}	56.07^{d}	80.07^{d}
T5	16.76^{ab}	27.11	127.95^{bc}	209.79^{cd}	233.79^{cd}
T6	38.38^{a}	39.59	32.39^{d}	73.47^{d}	97.47^{d}
T7	16.70^{ab}	56.59	70.06^{cd}	383.06^{c}	430.39^{c}
T8	30.50^{ab}	34.21	178.56^{ab}	1821.42^{b}	1880.42^{b}
T9	16.83^{ab}	24.93	225.03^{a}	3108.48^{a}	3167.48^{a}
T10	7.45^{b}	26.51	118.70^{bc}	31.77^{d}	90.77^{d}
SEm±	2.77*	3.74^{ns}	14.45*	182.47*	184.39*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.1.5. Fresh weight of shoot

Analysis of variance revealed significant difference in fresh weight of shoot due to different treatments over time. Although, fresh weight of shoot at monthly intervals showed an increasing trend (Table 5). Data pertaining to 30 DAI fresh weights of shoots, treatments T4, T7, T9 and control (T10) were on par. The highest value (1.02 g) was recorded for seedlings treated with *F. mosseae* with 10 g inoculum (T1) and *G. intradices* with 50 g inoculum (T6) least (0.38 g) for *G. intradices* with 10 g inoculum (T4). At 60 DAI, there was no significant variation in fresh weight of shoots due to various treatments. At 90 DAI, treatments T1, T2 and T6 were on par. The highest (2.63 g) fresh weight of shoot was observed in *G. proliferum* with 50 g inoculum (T9) and least (0.76 g) for *F. mosseae* with 50 g inoculum (T3). At 120 DAI, all except T8 and T9 were on par with other treatments. The highest (47.19 g) fresh weight of shoot was observed in *G. proliferum* with 50 g inoculum (T9) and least (0.94 g) for *F. mosseae* with 50 g inoculum (T3). At the end of the study, all except T8 and T9 were on with other treatments. Data pertaining to fresh weight of shoot, the highest value was (48.29 g) recorded for *G. proliferum* with 50 g inoculum (T9) next higher and comparable results were shown by *G. proliferum* with 25 g inoculum (T8) (20.35 g). The least (1.86 g) fresh weight of shoot occurred in control (T10) at the end of the study.

Table 5. Fresh weight of shoot (g) of *Tectona grandis* as influenced by different treatments at monthly intervals

Fresh weight of shoot (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	1.02^{a}	0.78	1.13^{cd}	2.74^{c}	3.84^{c}
T2	0.63^{ab}	0.64	0.96^{cd}	0.95^{c}	1.98^{c}
T3	0.69^{ab}	0.62	0.76^{d}	0.94^{c}	2.04^{c}
T4	0.38^{b}	0.83	0.82^{d}	0.96^{c}	2.06^{c}
T5	0.62^{ab}	0.87	1.94^{abc}	1.72^{c}	2.82^{c}
T6	1.02^{a}	0.98	0.99^{cd}	0.93^{c}	2.03^{c}
T7	0.59^{b}	0.67	1.49^{bcd}	3.35^{c}	4.45^{c}
T8	0.70^{ab}	0.85	2.35^{ab}	19.25^{b}	20.35^{b}
T9	0.41^{b}	0.71	2.63^{a}	47.19^{a}	48.29^{a}
T10	0.46^{b}	0.67	1.48^{bcd}	1.43^{c}	1.86^{c}
SEm±	0.05*	0.05^{ns}	0.14*	2.67*	2.67*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.1.6. Dry weight of shoots

Analysis of variance revealed significant difference in dry weight of shoots due to different treatments over time. Meanwhile, dry weight of shoot at monthly intervals showed an increasing trend (Table 6). At 30 DAI, treatments T2, T3, T5, T7 and T8 were on par. The highest (0.31 g) dry weight of shoot was observed in *G. intradices* with 50 g inoculum (T6) and least (0.08 g) for control (T10). At 60 DAI, there was no significant variation in dry weight of shoots due to various treatments. At 90 DAI, treatments T1, T2, T4, T6 and control (T10) were on par with each other. The highest (0.78 g) dry weight of shoot was observed in *G. proliferum* with 25 g inoculum (T8) and least (0.24 g) for *F. mosseae* with 50 g inoculum (T3). At 120 DAI, all except T8 and T9 were on par with other treatments. The highest (12.71 g) dry weight of shoot was observed in *G. proliferum* with 50 g inoculum (T9) and least (0.28 g) for *G. intradices* with 50 g inoculum (T6). At the end of the study, all except T8 and T9 were on par with other treatments. Whereas, highest dry weight of shoots were (12.98 g) recorded for *G. proliferum* with 50 g inoculum (T9). The least (0.55 g) dry weight of shoots occurred in *G. intradices* with 50 g inoculum (T6) at the end of the study. Greater than 150 times increase of dry weight of shoot was observed in seedlings subjected to *G. proliferum* with 50 g inoculum compared to control.

Table 6. Dry weight of shoot (g) of *Tectona grandis* as influenced by different treatments at monthly intervals

Treatments	30 DAI	60 DAI	90 DAI	120 DAI	150 DAI
T1	0.24^{ab}	0.20	0.39^{cd}	0.79^{c}	1.06^{c}
T2	0.15^{bc}	0.18	0.29^{cd}	0.29^{c}	0.56^{c}
T3	0.16^{bc}	0.17	0.24^{d}	0.29^{c}	0.62^{c}
T4	0.08^{c}	0.22	0.27^{cd}	0.29^{c}	0.54^{c}
T5	0.13^{bc}	0.21	0.54^{abc}	0.51^{c}	0.78^{c}
T6	0.31^{a}	0.38	0.47^{cd}	0.28^{c}	0.55^{c}
T7	0.13^{bc}	0.20	0.50^{bcd}	1.11^{c}	1.38^{c}
T8	0.18^{bc}	0.22	0.78^{a}	5.06^{b}	5.33^{b}
T9	0.09^{c}	0.18	0.70^{ab}	12.71^{a}	12.98^{a}
T10	0.08^{c}	0.15	0.40^{cd}	1.28^{c}	1.55^{c}
SEm±	0.09*	0.08^{ns}	0.22*	3.89*	3.64*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.1.7. Fresh weight of leaves

Analysis of variance revealed significant difference in fresh weight of leaves due to different treatments over time. In general, fresh weight of leaves at monthly intervals showed an increasing trend (Table 7). At 30 DAI, treatments T2, T4, T5, T7, T9 and control (T10) were on par with other treatments. The highest (1.61 g) fresh weight of leaves was observed in *G. intradices* with 50 g inoculum (T6) and least (0.44 g) for control (T10). At 60 DAI, there was no significant variation in fresh weight of leaves due to various. At 90 DAI, treatments T2, T3 and T6 were on par. The highest (5.04 g) fresh weight of leaves was observed in *G. proliferum* with 50 g inoculum (T9) and least (1.03 g) for *F. mosseae* with 50 g inoculum (T3). At 120 DAI, all except T8 and T9 were on par with other treatments. The highest (63.59 g) fresh weight of leaves was observed in *G. proliferum* with 50 g inoculum (T9) and least (1.05 g) for *F. mosseae* with 50 g inoculum (T3). At the end of the study, all except T8 and T9 were on par with other treatments. Data pertaining to fresh weight of leaves, the highest value was (65.43 g) recorded for *G. proliferum* with 50 g inoculum (T9) next higher and comparable (35.83 g) fresh weight of leaves were obtained in *G. proliferum* with 25 g inoculum (T8). The least (2.74 g) fresh weight of leaves occurred in seedlings without AMF inoculation kept as control (T10) at the end of the study.

Table 7. Fresh weight of leaves (g) of *Tectona grandis* as influenced by different treatments at monthly intervals

Fresh weight of leaves (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	1.13^{ab}	1.38	3.14^{bc}	6.46^{c}	8.30^{c}
T2	0.69^{b}	1.08	1.42^{e}	1.60^{c}	3.44^{c}
T3	1.01^{ab}	1.01	1.03^{e}	1.05^{c}	2.89^{c}
T4	0.64^{b}	1.09	1.20^{de}	1.29^{c}	3.13^{c}
T5	0.68^{b}	1.08	3.55^{bc}	4.16^{c}	6.00^{c}
T6	1.61^{a}	1.45	1.10^{e}	1.76^{c}	3.60^{c}
T7	0.66^{b}	1.65	1.84^{de}	7.68^{c}	9.52^{c}
T8	1.11^{ab}	1.41	4.11^{ab}	33.99^{b}	35.83^{b}
T9	0.61^{b}	0.73	5.04^{a}	63.59^{a}	65.43^{a}
T10	0.44^{b}	0.82	2.59^{cd}	2.62^{c}	2.74^{c}
SEm±	0.09*	0.10^{ns}	0.29*	3.75*	3.23*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.1.8. Dry weight of leaves

Analysis of variance revealed significant difference in dry weight of leaves due to different treatments over time. However, dry weight of leaves at monthly intervals showed an increasing trend (Table 8). At 30 DAI, all except T6, T8 and control (T10) were on par. The highest (0.28 g) dry weight of leaves was observed in *G. proliferum* with 25 g inoculum (T8) and least (0.08 g) for control (T10). At 60 DAI, there was no significant variation in dry weight of leaves due to various treatments. At 90 DAI, all except treatments T5, T8, T9 and control (T10) were on par. The highest (1.48 g) dry weight of leaves was observed in *G. proliferum* with 50 g inoculum (T9) and least (0.29 g) for *F. mosseae* with 50 g inoculum (T3). At 120 DAI, treatments T2, T3, T4, T6 and control (T10) were on par. The highest (21.66 g) dry weight of leaves was observed in *G. proliferum* with 50 g inoculum (T9) and least (0.33 g) for *F. mosseae* with 50 g inoculum (T3). At the end of the study, treatments T2, T3, T4, T6 and control (T10) were on par with other treatments. Although seedling dry weight of leaves, the highest value was (22.50 g) recorded for *G. proliferum* with 50 g inoculum (T9) consequently by *G. proliferum* with 25 g inoculum (T8) (12.34 g). The least (1.15) dry weight of leaves occurred in seedlings without AMF inoculation kept as control (T10) at the end of the study.

Table 8. Dry weight of leaves (g) of *Tectona grandis* as influenced by different treatments at monthly intervals

Dry weight of leaves (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	0.23^{ab}	0.36	0.37^{c}	1.88^{cd}	2.72^{cd}
T2	0.15^{ab}	0.29	0.32^{c}	0.46^{d}	1.31^{d}
T3	0.23^{ab}	0.27	0.29^{c}	0.33^{d}	1.17^{d}
T4	0.14^{ab}	0.27	0.38^{c}	0.68^{d}	1.21^{d}
T5	0.15^{ab}	0.26	1.11^{ab}	1.27^{cd}	2.01^{cd}
T6	0.31^{a}	0.41	0.41^{c}	0.66^{d}	1.50^{d}
T7	0.17^{ab}	0.44	0.60^{c}	2.42^{c}	3.26^{c}
T8	0.28^{a}	0.31	1.08^{ab}	11.50^{b}	12.34^{b}
T9	0.14^{ab}	0.23	1.48^{a}	21.66^{a}	22.50^{a}
T10	0.08^{b}	0.28	0.77^{bc}	0.87^{d}	1.15^{d}
SEm±	0.02*	0.03^{ns}	0.08*	1.25*	1.62*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.2. Below-ground parameters

4.1.2.1. Tap root length

Analysis of variance revealed significant difference in tap root length due to different treatments over time. Data pertaining to tap root length at monthly intervals showed an increasing trend (Table 9). At 30 DAI, all except 136 and control (T10) were on par. The highest (21.67 cm) tap root length was observed in *G. intradices* with 50 g inoculum (T6) and least (10.33 cm) for control (T10). At 60 DAI, there was no significant variation in tap root length due to various treatments. At 90 DAI, treatments T1, T3, T4 and T7 were on par. The highest (29.00 cm) tap root length was observed in *G. proliferum* with 50 g inoculum (T9) and least (19.01 cm) for *F. mosseae* with 25 g inoculum (T2). At 120 DAI, treatments T1, T2, T3 and T4 were on par. The highest (47.00 cm) tap root length was observed in *G. proliferum* with 50 g inoculum (T9) and least (22.73 cm) for *F. mosseae* with 25 g inoculum (T2). At the end of the study, treatments T1, T2, T3 and T4 were on par. With regard to tap root length, the highest value was (52.00 cm) recorded for *G. proliferum* with 50 g inoculum (T9) next higher and comparable (45.13 cm) tap root length recorded in seedlings subjected to *G. proliferum* with 25 g inoculum (T8). The least (27.73 cm) tap root length occurred in seedlings subjected to *F. mosseae* with 25 g inoculum (T2) at the end of the study.

Table 9. Tap root length (cm) of *Tectona grandis* as influenced by different treatments at monthly intervals

Tap root length (cm)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	10.43^{b}	21.70	23.33^{bcd}	24.53^{d}	29.53^{d}
T2	15.00^{ab}	18.80	19.01^{d}	22.73^{d}	27.73^{d}
T3	19.67^{a}	20.13	22.23^{bcd}	25.30^{d}	30.30^{d}
T4	17.67^{ab}	18.51	21.33^{bcd}	23.33^{d}	28.33^{d}
T5	14.33^{ab}	15.13	25.67^{ab}	29.93^{cd}	34.93^{cd}
T6	21.67^{a}	22.00	27.33^{ab}	29.40^{cd}	34.40^{cd}
T7	14.00^{ab}	16.13	22.67^{bcd}	37.00^{bc}	42.00^{bc}
T8	13.67^{ab}	14.70	24.33^{abc}	39.00^{ab}	45.13^{ab}
T9	14.00^{ab}	19.87	29.00^{a}	47.00^{a}	52.00^{a}
T10	10.33^{b}	17.67	19.33^{cd}	29.53^{cd}	34.53^{cd}
SEm±	0.95*	0.76^{ns}	0.78*	1.58*	1.68*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.2.2. Number of lateral roots

Analysis of variance revealed significant difference in number of lateral roots due to different treatments over time. With regards to number of lateral roots at monthly intervals showed an increasing trend (Table 10). At 30 DAI treatments T2, T4, T7, T8 and T9 were on par. The highest (27.67) number of lateral roots was observed in *G. intradices* with 50 g inoculum (T6) and least (13.67) for control (T10). At 60 DAI, treatments T1, T2, T3 and T4 were on par. The highest (35.67) number of lateral roots was observed in *G. proliferum* with 10 g inoculum (T7) and least (15.63) for *G. proliferum* with 50 g inoculum (T9). At 90 DAI, all except T1 and control (T10) were on par with other treatments. The highest (35.67) number of lateral roots was observed in *G. proliferum* with 10 g inoculum (T7) and least (23.00) for control (T10). At 120 DAI, all except T1, T4 and T8 were on par. The highest (41.00) number of lateral roots was observed in *F. mosseae* with 10 g inoculum (T1) and least (28.67) for *G. intradices* with 10 g inoculum (T4). At the end of the study, all except T1, T4 and T8 were on par. With regard to number of lateral roots, the highest value was (45.00) recorded for *F. mosseae* with 10 g inoculum (T1). The least (32.33) number of lateral roots occurred in seedlings subjected to *G. intradices* with 10 g inoculum (T4) at the end of the study.

Table 10. Number of lateral roots of *Tectona grandis* as influenced by different treatments at monthly intervals

Number of lateral roots					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	27.33^{a}	27.67^{abc}	35.00^{a}	41.00^{a}	45.00^{a}
T2	24.67^{ab}	25.67^{abc}	34.00^{ab}	33.00^{ab}	37.00^{ab}
T3	27.33^{a}	24.67^{abc}	32.00^{ab}	32.33^{ab}	36.00^{ab}
T4	24.00^{ab}	25.67^{abc}	34.67^{ab}	28.67^{b}	32.33^{b}
T5	25.33^{a}	30.33^{ab}	32.67^{ab}	33.00^{ab}	37.00^{ab}
T6	27.67^{a}	22.00^{bc}	33.67^{ab}	35.33^{ab}	39.67^{ab}
T7	20.33^{ab}	35.67^{a}	28.67^{ab}	34.67^{ab}	38.67^{ab}
T8	23.33^{ab}	21.33^{bc}	30.67^{ab}	28.33^{b}	32.33^{b}
T9	23.67^{ab}	15.63^{c}	27.33^{ab}	36.00^{ab}	40.00^{ab}
T10	13.67^{b}	18.67^{bc}	23.00^{b}	32.67^{ab}	36.67^{ab}
SEm±	1.15*	1.45*	1.14*	0.67*	1.07*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.2.3. Fresh weight of roots

Analysis of variance revealed significant difference in fresh weight of roots due to different treatments over time. While, fresh weight of roots at monthly intervals showed an increasing trend (Table 11). At 30 DAI, treatments T1, T5, T7 and T8 were on par. The highest (3.15 g) fresh weight of roots was observed in *G. intradices* with 50 g inoculum (T6) and least (0.88 g) for control (T10). At 60 DAI, all except T1 and T9 were on par. The highest (5.77 g) fresh weight of roots was observed in *F. mosseae* with 10 g inoculum (T1) and least (1.98) for *G. proliferum* with 50 g inoculum (T9). At 90 DAI, all except treatments T3 and T8 were on par. The highest (9.12 g) fresh weight of roots was observed in *G. proliferum* with 25 g inoculum (T8) and least (4.82 g) for *F. mosseae* with 50 g inoculum (T3). At 120 DAI, treatments T1, T2, T3, T4, T5, T6 and control (T10) were on par. The highest (33.85 g) fresh weight of roots was observed in *G. proliferum* with 50 g inoculum (T9) and least (6.02 g) for *G. intradices* with 10 g inoculum (T4). At the end of the study, treatments T1, T2, T3, T5, T6 and control (T10) were on par with other treatments. With regard to fresh weight of roots, the highest value was (36.06 g) recorded for *G. proliferum* with 50 g inoculum (T9) lower and comparable (20.35 g) fresh weight of roots by *G. proliferum* with 25 g inoculum (T8). The least (6.65 g) fresh weight of roots occurred in seedlings kept as control without AMF inoculation (T10) at the end of the study.

Table 11. Fresh weight of roots (g) of *Tectona grandis* as influenced by different treatments at monthly intervals

Fresh weight of roots (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	2.03^{abc}	5.77^{a}	6.55^{ab}	8.09^{cd}	10.30^{cd}
T2	1.38^{bc}	3.04^{ab}	5.61^{ab}	6.19^{cd}	8.40^{cd}
T3	2.69^{ab}	4.26^{ab}	4.82^{b}	6.32^{cd}	8.53^{cd}
T4	1.11^{c}	4.03^{ab}	5.34^{ab}	6.02^{cd}	6.65^{d}
T5	2.02^{abc}	3.71^{ab}	8.30^{ab}	6.48^{cd}	8.69^{cd}
T6	3.15^{a}	4.25^{ab}	7.57^{ab}	6.63^{cd}	8.84^{cd}
T7	1.76^{abc}	3.83^{ab}	7.58^{ab}	11.56^{c}	13.77^{c}
T8	2.39^{abc}	2.73^{ab}	9.12^{a}	18.14^{b}	20.35^{b}
T9	1.20^{bc}	1.98^{b}	8.33^{ab}	33.85^{a}	36.06^{a}
T10	0.88^{c}	3.09^{ab}	6.11^{ab}	6.31^{cd}	8.52^{cd}
SEm±	0.18*	0.32*	0.41*	1.67*	1.81*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.2.4. Dry weight of roots

Analysis of variance revealed significant difference in dry weight of roots due to different treatments over time. In general, dry weight of roots at monthly intervals showed an increasing trend (Table 12). At 30 DAI, treatments T1, T5, T7 and T8 were on par. The highest (0.56 g) dry weight of roots was observed in *G. intradices* with 50 g inoculum (T6) and least (0.11 g) for control (T10). At 60 DAI and 90 DAI, there was no significant variation in dry weight of roots due to various treatments. At 120 DAI, all except treatments T7, T8 and T9 were on par. The highest (11.43 g) dry weight of roots was observed in *G. proliferum* with 50 g inoculum (T9) and least (1.51 g) for *F. mosseae* with 25 g inoculum (T2). At the end of the study, all except T7, T8 and T9 were on par with other treatments. With regard to dry weight of roots, the highest value was (12.05 g) recorded for *G. proliferum* with 50 g inoculum (T9). Next lower and comparable (5.18 g) dry weight was observed in *G. proliferum* with 25 g inoculum (T8). The least (2.13 g) dry weight of roots occurred in seedlings subjected to *F. mosseae* with 25 g inoculum (T2) at the end of the study. Greater than fivefold increase number of lateral roots was observed in seedlings subjected to *G. proliferum* with 50 g inoculum compared to *F. mosseae* with 25 g inoculum.

Table 12. Dry weight of roots (g) of *Tectona grandis* as influenced by different treatments at monthly intervals

Dry weight of roots (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	0.37^{abc}	1.44	1.76	1.85^{c}	2.47^{c}
T2	0.20^{bc}	0.59	1.39	1.51^{c}	2.13^{c}
T3	0.44^{ab}	0.84	1.14	1.56^{c}	2.18^{c}
T4	0.17^{bc}	0.87	1.50	1.62^{c}	1.79^{c}
T5	0.35^{abc}	0.84	2.14	1.59^{c}	2.21^{c}
T6	0.56^{a}	0.95	2.05	1.63^{c}	2.25^{c}
T7	0.28^{abc}	0.85	1.91	3.38^{bc}	4.00^{bc}
T8	0.40^{abc}	0.53	1.89	4.56^{b}	5.18^{b}
T9	0.18^{bc}	0.74	1.94	11.43^{a}	12.05^{a}
T10	0.11^{c}	0.60	1.41	1.74^{c}	2.36^{c}
SEm±	0.04*	0.09^{ns}	0.12^{ns}	0.58*	0.61*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.2.5. Total fresh weight

Analysis of variance revealed significant difference in total fresh weight due to different treatments over time. Consequently, total fresh weight at monthly intervals showed an increasing trend (Table 13). At 30 DAI, all except treatments T2, T4, T7, T9 and control (T10) were on par. The highest (5.78 g) total fresh weight was observed in *G. intradices* with 50 g inoculum (T6) and least (1.78 g) for control (T10). At 60 DAI, there was no significant variation in total fresh weight due to various treatments. At 90 DAI, treatments T1, T2, T3 and T4 were on par. The highest (16.00 g) total fresh weight was observed in *G. proliferum* with 50 g inoculum (T9) and least (6.62 g) for *F. mosseae* with 50 g inoculum (T3). At 120 DAI, all except T8 and T9 were on par with other treatments. The highest (144.63 g) total fresh weight was observed in *G. proliferum* with 50 g inoculum (T9) and least (7.31 g) for *G. intradices* with 10 g inoculum (T4). At the end of the study, all except T8 and T9 were on par with other treatments. With regard to total fresh weight, the highest value was (149.78 g) recorded for *G. proliferum* with 50 g inoculum (T9) next higher and comparable total fresh weight was recorded in the seedling subjected to *G. proliferum* with 25 g inoculum (T8) (76.53). The least (11.83 g) total fresh weight occurred in seedlings treated with *G. intradices* with 10 g inoculum (T4) at the end of the study. Greater than 13 fold increase total fresh weight was observed in seedlings subjected to *G. proliferum* with 50 g inoculum compared to *G. intradices* with 10 g inoculum.

Table 13. Total fresh weight (g) of *Tectona grandis* as influenced by different treatments at monthly intervals

Total fresh weight (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	4.17^{ab}	7.94	8.74^{c}	17.29^{c}	22.44^{c}
T2	2.70^{b}	4.77	7.45^{c}	8.68^{c}	13.83^{c}
T3	4.39^{ab}	5.85	6.68^{c}	8.30^{c}	13.45^{c}
T4	2.13^{b}	5.94	7.31^{c}	7.31^{c}	11.83^{c}
T5	3.31^{ab}	5.66	13.79^{ab}	12.36^{c}	17.51^{c}
T6	5.78^{a}	6.69	9.32^{bc}	9.50^{c}	14.47^{c}
T7	3.01^{b}	6.16	10.91^{bc}	22.59^{c}	27.74^{c}
T8	4.20^{ab}	4.55	15.58^{b}	71.38^{b}	76.53^{b}
T9	2.23^{b}	3.42	16.00^{a}	144.63^{a}	149.78^{a}
T10	1.78^{b}	4.59	7.98^{c}	10.18^{c}	13.13^{c}
SEm±	0.30*	0.42^{ns}	0.71*	7.99*	8.14*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.2.6. Total dry weight

Analysis of variance revealed significant difference in total dry weight due to different treatments over time. However, total dry weight at monthly intervals showed an increasing trend (Table 14). At 30 DAI, all except treatments T1, T3, T5, T6 and T8 were on par. The highest (1.19 g) total dry weight was observed in *G. intradices* with 50 g inoculum (T6) and least (0.28 g) for control (T10). At 60 DAI, there was no significant variation in total dry weight due to various treatments. At 90 DAI, treatments T5, T7 and T8 were on par. The highest (4.12 g) total dry weight was observed in *G. proliferum* with 50 g inoculum (T9) and least (1.67 g) for *F. mosseae* with 50 g inoculum (T3). At 120 DAI, all except T8 and T9 were on par with other treatments. The highest (45.80 g) total dry weight was observed in *G. proliferum* with 50 g inoculum (T9) and least (2.18 g) for *F. mosseae* with 50 g inoculum (T3). At the end of the study, all except treatments T8 and T9 were on par with other treatments. Exploration of data indicated that total dry weight was highest (47.53 g) recorded for *G. proliferum* with 50 g inoculum (T9) next higher and comparable total fresh weight was recorded in the seedling subjected to *G. proliferum* with 25 g inoculum (T8) (22.85 g). The least (3.56 g) total dry weight occurred in seedlings treated with *G. intradices* with 10 g inoculum (T4) at the end of the sudy. Greater than 13 times increase total dry weight was observed in seedlings subjected to *G. proliferum* with 50 g inoculum compared to *G. intradices* with 10 g inoculum.

Table 14. Total dry weight (g) of *Tectona grandis* as influenced by different treatments at monthly intervals

Total dry weight (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	0.85^{ab}	2.00	2.52^{bc}	4.52^{c}	6.25^{c}
T2	0.50^{b}	1.06	1.96^{c}	2.26^{c}	4.00^{c}
T3	0.84^{ab}	1.28	1.67^{c}	2.18^{c}	3.91^{c}
T4	0.39^{b}	1.36	2.15^{c}	2.94^{c}	3.56^{c}
T5	0.63^{ab}	1.31	3.79^{ab}	4.17^{c}	5.00^{c}
T6	1.19^{a}	1.64	2.72^{bc}	3.408^{c}	4.31^{c}
T7	0.58^{b}	1.49	3.01^{ab}	6.91^{c}	8.64^{c}
T8	0.86^{ab}	1.06	3.74^{ab}	21.12^{b}	22.85^{b}
T9	0.42^{b}	1.15	4.12^{a}	45.80^{a}	47.53^{a}
T10	0.28^{b}	1.03	2.59^{bc}	3.33^{c}	5.06^{c}
SEm±	0.07*	0.13^{ns}	0.18*	2.50*	2.76*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.2.7. Shoot-root length ratio

Analysis of variance revealed significant difference in shoot-root length ratio due to different treatments over time. In, shoot-root length ratio at monthly intervals showed an increasing trend with few exceptions (Table 15). At 30 DAI, all except T1 and T3 were on par with other treatments. The highest (1.20) shoot-root length ratio was observed in *F. mosseae* with 10 g inoculum (T1) and least (0.51) for *F. mosseae* with 50 g inoculum (T3). At 60 DAI, there was no significant variation in shoot-root length ratio due to various treatments. At 90 DAI, treatments T1, T7, T8 and control (T10) were on par. The highest (0.76) shoot-root length ratio was observed in *F. mosseae* with 25 g inoculum (T2) and least (0.55) for *G. intradices* with 25 g inoculum (T5). At 120 DAI, all except treatment T9 were on par with other treatments. The highest (1.22) shoot-root length ratio was observed in *G. proliferum* with 50 g inoculum (T9) and least (0.37) for control (T10). At the end of the study, treatments T2, T3, T4 and T5 were on par. With regard to shoot-root length ratio, the highest value was (1.17) recorded for *G. proliferum* with 50 g inoculum (T9). The least shoot-root length ratio occurred in seedlings kept as control (T10) without AMF inoculation (0.42) at the end of the study (150 DAI). Greater than threefold increase shoot-root length ratio was observed in seedlings subjected to *G. proliferum* with 50 g inoculum compared to control.

Table 15. Shoot-root length ratio of *Tectona grandis* as influenced by different treatments at monthly intervals

Shoot-root length ratio					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	1.20^{a}	0.68	0.62^{ab}	0.71^{b}	0.69^{b}
T2	0.78^{ab}	0.71	0.76^{a}	0.48^{b}	0.53^{bc}
T3	0.51^{b}	0.65	0.56^{b}	0.51^{b}	0.54^{bc}
T4	0.60^{ab}	0.60	0.57^{b}	0.49^{b}	0.53^{bc}
T5	0.80^{ab}	0.72	0.55^{b}	0.48^{b}	0.51^{bc}
T6	0.66^{ab}	0.88	0.40^{c}	0.44^{b}	0.48^{c}
T7	0.95^{ab}	0.76	0.62^{ab}	0.46^{b}	0.49^{c}
T8	0.86^{ab}	0.79	0.63^{ab}	0.70^{b}	1.02^{b}
T9	0.82^{ab}	0.61	0.52^{bc}	1.22^{a}	1.17^{a}
T10	1.03^{ab}	0.67	0.64^{ab}	0.37^{b}	0.42^{c}
SEm±	0.06*	0.03^{ns}	0.02*	0.05*	0.05*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.2.8. Shoot-root biomass ratio

Analysis of variance revealed significant difference in shoot-root biomass ratio due to different treatments over time. Similarly, shoot-root biomass ratio at monthly intervals showed an increasing trend with few exceptions (Table 16). At 30 DAI, treatments T4, T6, T7, T8 and T9 were on par. The highest (1.51) shoot-root biomass ratio was observed in *F. mosseae* with 25 g inoculum (T2) and least (0.93) for *G. intradices* with 25 g inoculum (T5). At 60 DAI, treatments T2, T4, T6, T7, T9 and control (T10) were on par. The highest (1.16) shoot-root biomass ratio was observed in *G. proliferum* with 25 g inoculum (T8) and least (0.45) for *F. mosseae* with 10 g inoculum (T1). At 90 DAI, all except treatments T5, T8, T9 and control (T10) were on par. The highest (1.32) shoot-root biomass ratio was observed in *G. proliferum* with 50 g inoculum (T9) and least (0.40) for *G. intradices* with 50 g inoculum (T6). At 120 DAI, all except T8 and T9 were on par with other treatments. The highest (4.02) shoot-root biomass ratio was observed in *G. proliferum* with 25 g inoculum (T8) and least (0.40) for *F. mosseae* with 50 g inoculum (T3). At the end of the study, all except T8 and T9 were on par with other treatments. With regard to shoot-root biomass ratio, the highest value was (4.02) recorded for *G. proliferum* with 25 g inoculum (T8). The least (0.80) shoot-root biomass ratio occurred in seedlings subjected to *F. mosseae* with 50 g inoculum (T3) at the end of the study. Greater than 10 fold increase shoot-root biomass

ratio was observed in seedlings subjected to *G. proliferum* with 25 g inoculum compared to control.

Table 16. Shoot-root biomass ratio of *Tectona grandis* as influenced by different treatments at monthly intervals

Shoot-root biomass ratio					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	1.41^{a}	0.45^{b}	0.44^{b}	1.43^{b}	1.52^{b}
T2	1.51^{a}	0.79^{ab}	0.50^{b}	0.50^{b}	0.89^{b}
T3	0.91^{c}	0.52^{b}	0.54^{b}	0.40^{b}	0.80^{b}
T4	1.35^{abc}	0.76^{ab}	0.56^{b}	0.53^{b}	1.01^{b}
T5	0.93^{bc}	0.63^{b}	0.78^{ab}	1.10^{b}	1.30^{b}
T6	1.16^{abc}	0.74^{ab}	0.40^{b}	0.71^{b}	1.00^{b}
T7	1.16^{abc}	0.79^{ab}	0.67^{b}	1.00^{b}	1.14^{b}
T8	1.14^{abc}	1.16^{a}	1.00^{ab}	4.02^{a}	3.69^{a}
T9	1.36^{abc}	0.80^{ab}	1.32^{a}	3.04^{a}	2.97^{a}
T10	1.40^{ab}	0.92^{ab}	0.89^{ab}	0.85^{b}	1.11^{b}
SEm±	0.05*	0.05*	0.07*	0.24*	0.19*

**Significant at 0.05 levels*
Values with same superscript in column at different month are homogenous

4.1.2.9. Vigour Index I

Analysis of variance revealed significant difference in vigour index I due to different treatments over time. Meanwhile, vigour index I at monthly intervals showed an increasing trend (Table 17). At 30 DAI, all except T3, T4 and T6 were on par with other treatments. The highest (18.47) vigour index I was observed in *G. intradices* with 50 g inoculum (T6) and least (10.91) for *F. mosseae* with 10 g inoculum (T1). At 60 DAI, all except T1, T4, T5, T6 and T8 were on par with other treatments. The highest (18.74) vigour index I was observed in *F. mosseae* with 10 g inoculum (T1) and least (13.58) for *G. intradices* with 25 g inoculum (T5). At 90 DAI, treatments T1, T3, T4 and T7 were on par. The highest (22.90) vigour index I was observed in *G. proliferum* with 50 g inoculum (T9) and least (16.53) for *F. mosseae* with 25 g inoculum (T2). At 120 DAI, all except T8 and T9 were on par. The highest (101.72) vigour index I was observed in *G. proliferum* with 25 g inoculum (T8) and least (17.42) for *F. mosseae* with 25 g inoculum (T2). At the end of the study, treatments T1, T3, T4, T6 and control (T10) were on par. With regard to vigour index I, the highest value was (58.87) recorded for *G. proliferum* with 50 g inoculum (T9). Exploration of data indicated that the next higher and comparable (47.51) vigour index I recorded in the seedlings subjected to *G. proliferum* with 25 g inoculum (T8). The least (21.91) vigour index I

occurred in seedlings subjected to *F. mosseae* with 25 g inoculum (T2) at the end of the study. Greater than twofold increase vigour index I was observed in seedlings subjected to *G. proliferum* with 50 g inoculum compared to control.

Table 17. Vigour Index I of *Tectona grandis* as influenced by different treatments at monthly intervals

Vigour Index I					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	10.91^{b}	18.74^{a}	17.96^{bc}	21.49^{b}	25.83^{de}
T2	13.56^{b}	16.52^{ab}	16.53^{c}	17.42^{b}	21.91^{e}
T3	15.40^{ab}	14.57^{ab}	18.00^{bc}	19.87^{b}	24.36^{de}
T4	14.08^{ab}	13.65^{b}	17.42^{bc}	18.10^{b}	22.59^{de}
T5	13.45^{b}	13.58^{b}	20.68^{ab}	23.06^{b}	27.55^{d}
T6	18.47^{a}	13.97^{b}	19.94^{abc}	21.88^{b}	26.38^{de}
T7	13.17^{b}	14.67^{ab}	19.11^{bc}	28.14^{b}	32.63^{c}
T8	13.35^{b}	13.71^{b}	20.64^{ab}	101.72^{a}	47.51^{b}
T9	12.62^{b}	16.11^{ab}	22.90^{a}	54.38^{ab}	58.87^{a}
T10	10.94^{b}	14.60^{ab}	16.57^{c}	21.09^{b}	25.58^{de}
SEm±	0.55*	0.45*	0.45*	6.77*	2.19*

**Significant at 0.05 levels*
Values with same superscript in column at different month are homogenous

4.1.2.10. Vigour Index II

Analysis of variance revealed significant difference in vigour index II due to different treatments over time. Although, vigour index II at monthly intervals showed an increasing trend (Table 18). At 30 DAI, treatments T2, T4, T7, T9 and control (T10) were on par. The highest (0.62) vigour index II was observed in *G. intradices* with 50 g inoculum (T6) and least (0.15) for control (T10). At 60 DAI, there was no significant variation in vigour index II due to various treatments. At 90 DAI, treatments T2, T3 and T4 were on par. The highest (2.15) vigour index II was observed in *G. proliferum* with 50 g inoculum (T9) and least (1.02) for *F. mosseae* with 25 g inoculum (T2). At 120 DAI, all except T8 and T9 were on par with other treatments. The highest (23.91) vigour index II was observed in *G. proliferum* with 50 g inoculum (T9) and least (0.96) for *G. intradices* with 10 g inoculum (T4). A similar trend was followed in next month vigour index II. At the end of the study, all except T8 and T9 were on par with other treatments. With regard to vigour index II, the highest value was (24.82) recorded for *G. proliferum* with 50 g inoculum (T9). The least (1.86) vigour index II occurred in seedlings treated with *G. intradices* with 10 g inoculum (T4) at the end of the study.

Table 18. Vigour Index II of *Tectona grandis* as influenced by different treatments at monthly intervals

Vigour Index II					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	0.44^{ab}	1.05	1.32^{bc}	2.36^{c}	3.26^{c}
T2	0.26^{c}	0.55	1.02^{c}	1.18^{c}	2.09^{c}
T3	0.44^{ab}	0.67	0.87^{c}	1.14^{c}	2.04^{c}
T4	0.20^{c}	0.71	1.12^{c}	0.96^{c}	1.86^{c}
T5	0.33^{ab}	0.68	1.98^{ab}	1.76^{c}	2.61^{c}
T6	0.62^{a}	0.85	1.42^{bc}	1.35^{c}	2.25^{c}
T7	0.30^{c}	0.78	1.57^{abc}	3.60^{c}	4.51^{c}
T8	0.45^{ab}	0.55	1.96^{ab}	11.03^{b}	11.93^{b}
T9	0.22^{c}	0.60	2.15^{a}	23.91^{a}	24.82^{a}
T10	0.15^{c}	0.54	1.35^{bc}	1.74^{c}	2.64^{c}
SEm±	0.04*	0.07^{ns}	0.10*	1.31*	1.31*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.3. Physiological observations

4.1.3.1. Leaf Area Ratio

Analysis of variance revealed significant difference in leaf area ratio due to different treatments over time at five per cent level. Exploration of data indicated that, leaf area ratio at monthly intervals showed a decreasing trend (Table 19). At 30 DAI, there was no significant variation in leaf area ratio due to various treatments. At 60 DAI, all except T1, T3 and T7 were on par. The highest (35.13 cm^2g^{-1}) leaf area ratio was observed in *G. proliferum* with 10 g inoculum (T7) and least (13.71 cm^2g^{-1}) for *F. mosseae* with 10 g inoculum (T1). At 90 DAI, treatments T3, T4, T6 and T7 were on par. The highest (55.20 cm^2g^{-1}) leaf area ratio was observed in *G. proliferum* with 50 g inoculum (T9) and least (9.65 cm^2g^{-1}) for *F. mosseae* with 25 g inoculum (T2). At 120 DAI, treatments T2, T3, T4 and T6 were on par. The highest (86.30 cm^2g^{-1}) leaf area ratio was observed in *G. proliferum* with 25 g inoculum (T8) and least (10.20 cm^2g^{-1}) for control (T10). At the end of the study, treatments T2, T3, T4, T6 and control (T10) were on par. With regard to leaf area ratio, the highest value was (82.34 cm^2 g^{-1}) recorded for *G. proliferum* with 25 g inoculum (T8). The least (15.81) leaf area ratio occurred in seedlings subjected to *F. mosseae* with 50 g inoculum (T3) at the end of the study.

Table 19. Leaf Area Ratio ($cm^2\ g^{-1}$) of *Tectona grandis* as influenced by different treatments at monthly intervals

Leaf Area Ratio ($cm^2\ g^{-1}$)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	27.58	13.71^{b}	10.31^{d}	73.52^{ab}	56.47^{bc}
T2	24.78	17.05^{ab}	9.65^{d}	25.33^{de}	20.57^{e}
T3	31.45	14.98^{b}	13.58^{cd}	17.31^{de}	15.81^{e}
T4	27.44	21.05^{ab}	14.43^{cd}	29.66^{de}	21.77^{e}
T5	26.79	20.25^{ab}	32.12^{bc}	58.17^{c}	42.58^{d}
T6	32.46	23.25^{ab}	13.72^{cd}	28.74^{de}	22.63^{e}
T7	27.49	35.13^{a}	25.62^{cd}	54.18^{c}	48.94^{cd}
T8	30.79	30.92^{ab}	48.01^{ab}	86.30^{a}	82.34^{a}
T9	39.23	30.02^{ab}	55.20^{a}	68.79^{bc}	67.48^{b}
T10	24.34	32.37^{ab}	45.95^{ab}	10.20^{e}	19.06^{e}
SEm±	1.56^{ns}	1.99*	3.47*	4.79*	4.27*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.3.2. Leaf Weight Ratio

Analysis of variance revealed significant difference in leaf weight ratio due to different treatments over time. In general, leaf weight ratio at monthly intervals showed a decreasing trend with few exceptions (Table 20). At 30 DAI and 60 DAI, there was no significant variation in leaf weight ratio due to various treatments. At 90 DAI, all except T4, T5, T7, T8, T9 and control (T10) were on par. The highest (0.37 cm^2g^{-1}) leaf area ratio was observed in *G. proliferum* with 50 g inoculum (T9) and least (0.15 cm^2g^{-1}) for *F. mosseae* with 10 g inoculum (T1). At 120 DAI, treatments T2, T3 and T4 were on par. The highest (0.55 cm^2g^{-1}) leaf area ratio was observed in *G. proliferum* with 25 g inoculum (T8) and least (0.11 cm^2g^{-1}) for control (T10). At the end of the study, treatments T4, T6 and T7 were on par. With regard to leaf weight ratio, the highest value was (0.54 cm^2g^{-1}) recorded for *G. proliferum* with 25 g inoculum (T8). The least (0.25 cm^2g^{-1}) leaf weight ratio occurred in seedlings without AMF inoculation kept as control (T10) at the end of the study. Greater than 100 per cent increase leaf weight ratio was observed in seedlings subjected to *G. proliferum* with 25 g inoculum compared to control.

Table 20. Leaf Weight Ratio (cm^2g^{-1}) of *Tectona grandis* as influenced by different treatments at monthly intervals

Leaf Weight Ratio (cm^2g^{-1})					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	0.28	0.19	0.15^{b}	0.41^{bc}	0.43^{bc}
T2	0.30	0.27	0.16^{b}	0.20^{ef}	0.33^{def}
T3	0.28	0.21	0.19^{b}	0.15^{ef}	0.30^{ef}
T4	0.33	0.24	0.21^{ab}	0.19^{ef}	0.35^{cde}
T5	0.25	0.21	0.28^{ab}	0.36^{bcd}	0.40^{bcd}
T6	0.26	0.24	0.17^{b}	0.27^{de}	0.35^{cde}
T7	0.28	0.29	0.22^{ab}	0.33^{cd}	0.37^{cde}
T8	0.32	0.31	0.28^{ab}	0.55^{a}	0.54^{a}
T9	0.35	0.27	0.37^{a}	0.48^{ab}	0.48^{ab}
T10	0.24	0.28	0.30^{ab}	0.11^{f}	0.25^{f}
SEm±	0.01^{ns}	0.01^{ns}	0.02*	0.03*	0.02*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.3.3. Specific Leaf Area

Analysis of variance revealed significant difference in specific leaf area due to different treatments over time. Data pertaining to specific leaf area at monthly intervals showed a decreasing trend with few exceptions (Table 21). At 30 DAI, there was no significant variation in specific leaf area due to various treatments. At 60 DAI, all except T2, T7, T9 and control (T10) were on par with other treatments. The highest (117.47 cm^2g^{-1}) specific leaf area was observed in *G. proliferum* with 10 g inoculum (T7) and least (62.16 cm^2g^{-1}) for *F. mosseae* with 25 g inoculum (T2). At 90 DAI, treatments T1, T2 and T4 were on par. The highest (176.78 cm^2g^{-1}) specific leaf area was observed in *G. proliferum* with 25 g inoculum (T8) and least (56.11 cm^2g^{-1}) for *F. mosseae* with 25 g inoculum (T2). At 120 DAI, treatments T4, T5, T8 and T9 were on par. The highest (180.93 cm^2g^{-1}) specific leaf area was observed in *F. mosseae* with 10g soil inoculum containing 10 g inoculum (T1) and least (96.22 cm^2g^{-1}) for control (T10). At the end of the study, all except T1, T5, T7, T8 and T9 were on par. With regard to specific leaf area, the highest value was (152.33 cm^2g^{-1}) occurred in seedlings subjected to *G. proliferum* with 25 g inoculum (T8). Whereas, the least (52.99) specific leaf area occurred in seedlings subjected to *F. mosseae* with 50 g inoculum (T3) at the end of the study.

Table 21. Specific Leaf Area (cm^2g^{-1}) of *Tectona grandis* as influenced by different treatments at monthly intervals

Specific Leaf Area (cm^2g^{-1})					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	100.17	73.25^{ab}	67.18^{d}	180.93^{a}	130.47^{ab}
T2	82.47	62.16^{b}	56.11^{d}	125.04^{bcd}	62.75^{c}
T3	113.15	70.33^{ab}	70.02^{cd}	118.08^{cd}	52.99^{c}
T4	80.50	96.12^{ab}	63.94^{d}	162.70^{abc}	63.91^{c}
T5	108.16	99.80^{ab}	111.83^{bc}	162.51^{abc}	105.83^{b}
T6	122.94	97.44^{ab}	82.42^{cd}	117.48^{cd}	65.03^{c}
T7	95.85	117.47^{a}	111.06^{bc}	166.61^{ab}	133.75^{ab}
T8	96.91	103.02^{ab}	176.78^{a}	158.32^{abc}	152.33^{a}
T9	111.86	110.47^{a}	149.24^{ab}	144.19^{abc}	141.39^{a}
T10	121.08	113.74^{a}	155.27^{a}	96.22^{d}	78.20^{c}
SEm±	5.55^{ns}	5.03*	8.44*	6.09*	7.15*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.3.4. Specific Leaf Weight

Analysis of variance revealed significant difference in specific leaf weight due to different treatments over time. Although, specific leaf weight at monthly intervals showed a decreasing trend with few exceptions (Table 22). At 30 DAI, there was no significant variation in specific leaf weight due to various treatments. At 60 DAI, all except T1, T2 and T3 were on par with other treatments. The highest (0.017 g cm^{-2}) specific leaf weight was observed in *F. mosseae* with 25 g inoculum (T2) and least (0.009 g cm^{-2}) for *G. proliferum* with 10 g inoculum (T7) and *G. proliferum* with 50 g inoculum (T9). At 90 DAI, treatments T8 and control (T10) were on par. The highest (0.019 g cm^{-2}) specific leaf weight was observed in *F. mosseae* with 25 g inoculum (T2) and least (0.006 g cm^{-2}) for *G. proliferum* with 25 g inoculum (T8) and control (T10). At 120 DAI, treatments T5, T7 and T9 were on par. The highest (0.011 g cm^{-2}) specific leaf weight was observed in control (T10) and least (0.006 g cm^{-2}) for *F. mosseae* with 10 g inoculum (T1), *G. intradices* with 10 g inoculum (T4) and *G. proliferum* with 25 g inoculum (T8). At the end of the study, treatments T1, T7, T8 and T9 were on par. With regard to specific leaf weight, the highest value was (0.019 g cm^{-2}) recorded for *F. mosseae* with 50 g inoculum (T3). The least (0.007) specific leaf weight occurred in seedlings treated with *G. proliferum* with 50 g inoculum (T9) and *G. proliferum* with 25 g inoculum (T8) at the end of the study.

Table 22. Specific Leaf Weight (g cm^{-2}) of *Tectona grandis* as influenced by different treatments at monthly intervals

Specific Leaf Weight (g cm^{-2})					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	0.010	0.015^{ab}	0.016^{ab}	0.006^{c}	0.008^{d}
T2	0.012	0.017^{a}	0.019^{a}	0.008^{abc}	0.017^{ab}
T3	0.010	0.014^{ab}	0.015^{abc}	0.009^{abc}	0.019^{a}
T4	0.014	0.011^{b}	0.017^{ab}	0.006^{c}	0.016^{ab}
T5	0.009	0.010^{b}	0.009^{cde}	0.006^{bc}	0.010^{cd}
T6	0.008	0.010^{b}	0.012^{bcd}	0.009^{ab}	0.016^{ab}
T7	0.011	0.009^{b}	0.009^{cde}	0.006^{bc}	0.008^{d}
T8	0.011	0.010^{b}	0.006^{e}	0.006^{c}	0.007^{d}
T9	0.009	0.009^{b}	0.007^{de}	0.007^{bc}	0.007^{d}
T10	0.009	0.010^{b}	0.006^{e}	0.011^{a}	0.013^{bc}
SEm±	0.001^{ns}	0.001*	0.001*	0.000*	0.001*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.3.5. Absolute Growth Rate

Analysis of variance revealed significant difference in absolute growth rate due to different treatments over time. Meanwhile, absolute growth rate at monthly intervals showed an increasing trend with few exceptions (Table 23). At 60 DAI, there was no significant variation in absolute growth rate due to various treatments. At 90 DAI, all except treatments T6, T8 and T9 were on par. The highest (0.13 cm day^{-1}) absolute growth rate was observed in *G. proliferum* with 50 g inoculum (T9) and least (-0.05 cm day^{-1}) for *G. intradices* with 50 g inoculum (T6). Similarly at 120 DAI, all except T3, T4, T5 and T6 were on par with other treatments. The highest (1.41 cm day^{-1}) absolute growth rate was observed in *G. proliferum* with 50 g inoculum (T9) and least (-0.10 cm day^{-1}) for *F. mosseae* with 25 g inoculum (T2). At the end of the study, there was no significant variation in absolute growth rate due to various treatments.

4.1.3.6. Relative Growth Rate

Analysis of variance revealed significant difference in relative growth rate due to different treatments over time. However, relative growth rate at monthly intervals showed an increasing trend with few exceptions (Table 24). At 60 DAI and 90 DAI, there was no significant variation in specific leaf weight due to various treatments. At 120 DAI, treatments T1, T2, T3, T4, T5, T6 and control (T10) were on par. The highest (0.03 g $g^{-1}day^{-1}$) relative growth rate was observed in *G. proliferum* with 50 g inoculum

(T9) and *G. proliferum* with 25 g inoculum (T8). Least specific leaf weight (-0.01 g $g^{-1}day^{-1}$) observed for *G. intradices* with 25 g inoculum (T5). At the end of the study, treatments T2, T3, T5 and T6 were on par. With regard to relative growth rate, the highest value was (0.01 g $g^{-1}day^{-1}$) recorded for *G. intradices* with 10 g inoculum (T4). The least (0.00) relative growth rate occurred in seedlings treated with *G. proliferum* with 25 g inoculum (T8) and *G. proliferum* with 50 g inoculum (T9) at the end of the study.

Table 23. Absolute growth rate (cm/day) of *Tectona grandis* as influenced by different treatments at monthly intervals

Absolute growth rate (cm/day)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	-	0.13	-0.04^{ab}	0.12^{c}	0.11
T2	-	0.06	0.03^{ab}	-0.10^{d}	0.12
T3	-	0.04	0.04^{ab}	0.02^{cd}	0.12
T4	-	0.01	0.08^{ab}	-0.02^{cd}	0.12
T5	-	-0.02	0.10^{ab}	0.01^{cd}	0.12
T6	-	-0.04	-0.05^{b}	0.06^{cd}	0.12
T7	-	0.02	0.07^{ab}	0.10^{c}	0.12
T8	-	-0.01	0.12^{a}	0.91^{b}	0.11
T9	-	0.03	0.13^{a}	1.41^{a}	0.12
T10	-	-0.01	0.07^{ab}	-0.05^{cd}	0.12
SEm±	-	0.02^{ns}	0.02*	0.09	0.00^{ns}

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

Table 24. Relative Growth rate (g $g^{-1}day^{-1}$) of *Tectona grandis* as influenced by different treatments at monthly intervals

Relative Growth rate (g $g^{-1}day^{-1}$)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	-	0.02	0.01	0.01^{bc}	0.00^{bc}
T2	-	0.01	0.01	0.00^{bc}	0.01^{ab}
T3	-	0.01	0.00	0.01^{bc}	0.01^{ab}
T4	-	0.02	0.01	0.00^{bc}	0.01^{a}
T5	-	0.01	0.02	-0.01^{c}	0.01^{ab}
T6	-	0.00	0.01	0.00^{bc}	0.01^{ab}
T7	-	0.01	0.01	0.01^{b}	0.00^{bc}
T8	-	0.00	0.02	0.03^{a}	0.00^{c}
T9	-	0.01	0.02	0.03^{a}	0.00^{c}
T10	-	0.02	0.02	0.00^{bc}	0.01^{bc}
SEm±	-	0.00^{ns}	0.00^{ns}	0.00*	0.00

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.3.7. Net Assimilation Rate

Analysis of variance revealed significant difference in net assimilation rate due to different treatments over time. Whereas, the net assimilation rate at monthly intervals showed a decreasing trend with few exceptions (Table 25). At 60 DAI, 90 DAI and 120 DAI, there was no significant variation in net assimilation rate due to various treatments. At the end of the study, all except treatments T4 and T9 were on par. With regard to net assimilation rate, the highest value was (0.00 g $g^{-1}day^{-1}$) recorded for *G. proliferum* with 50 g inoculum (T9) and least (-0.00) occurred in *G. intradices* with 10 g inoculum (T4) at the end of the study.

Table 25. Net Assimilation Rate (g $g^{-1}day^{-1}$) of *Tectona grandis* as influenced by different treatments at monthly intervals

Net Assimilation Rate (g $g^{-1}day^{-1}$)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	-	0.00	0.00	0.00	0.00^{ab}
T2	-	0.00	0.00	0.00	0.00^{ab}
T3	-	0.00	0.00	0.00	0.00^{ab}
T4	-	0.00	0.00	0.00	0.00^{b}
T5	-	0.00	0.00	0.00	0.00^{ab}
T6	-	0.00	0.00	0.00	0.00^{ab}
T7	-	0.00	0.00	0.00	0.00^{ab}
T8	-	0.00	0.00	0.00	0.00^{ab}
T9	-	0.00	0.00	0.00	0.00^{a}
T10	-	0.00	0.00	0.00	0.00^{ab}
SEm±	-	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.00*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.3.8. Physiological parameters

Analysis of variance revealed significant difference in chlorophyll content, photosynthetic rate, transpiration rate, leaf temperature, stomatal conductance, relative water content and plant water potential of the seedlings due different treatments (Table 26). With regards to chlorophyll content, the highest value was (42.13) recorded for seedling treated with *G. proliferum* with 50 g inoculum (T9) and the least (31.57) chlorophyll content was occurred in seedlings without AMF inoculation kept as control (T10). Meanwhile, highest photosynthetic rate (15.84 µmol $m^{-2}s^{-1}$) was recorded for seedlings inoculated with *F. mosseae* with 50 g inoculum (T3) and the lowest value (11.46) was observed in seedlings treated with *G. proliferum* with 25 g inoculum (T8). Transpiration rate was highest (2.96 µmol $m^{-2}s^{-1}$) in seedlings without AMF inoculation

kept as control (T10) and it was the lowest in *F. mosseae* with 10 g inoculum (T1) (2.33). However, the leaf temperature was the highest (32.80 ^{o}C) for the seedlings treated with *G. proliferum* with 50 g inoculum (T9) and lowest (31.90) value was recorded for the seedling subjected to *F. mosseae* with 10 g inoculum (T1). Data pertaining to the stomatal conductance, the highest value was (0.20) observed for seedlings treated with *G. intradices* with 50 g inoculum (T6) and the least (0.16) stomatal conductance was occurred in seedlings subjected to *F. mosseae* with 10 g inoculum (T1). Exploration of date indicated that, the highest value of relative water content was (80.08) observed for seedlings treated with *G. proliferum* with 50 g inoculum (T9) and the least (67.14) relative water content was occurred in seedlings kept as control (T10). Meanwhile, the highest value of plant water potential (1.84 MPa) was recorded for seedlings inoculated with *G. proliferum* with 10 g inoculum (T7) and the lowest (1.40) plant water potential was observed in seedlings subjected to *F. mosseae* with 10 g inoculum contain 10 g inoculum (T1).

Table 26. Physiological parameters of *Tectona grandis* as influenced by different treatments at 150 DAI

Treatments	Chlorophyll content	Photosynthesis rate (µmol m^{-2} s^{-1})	Transpiration rate (µmol m^{-2} s^{-1})	Leaf temperature (^{o}C)	Stomatal conductance (s cm^{-1})	Relative water content (%)	Plant water potential (MPa)
T1	36.07^{abcd}	12.56	2.33	31.90^{d}	0.16	74.31^{ab}	1.40
T2	40.67^{abc}	13.73	2.55	32.40^{bc}	0.17	75.55^{ab}	1.81
T3	35.60^{abcd}	15.84	2.88	32.60^{ab}	0.18	74.76^{ab}	1.58
T4	36.07^{abcd}	11.69	2.61	32.37^{c}	0.16	71.27^{ab}	1.80
T5	34.90^{bcd}	11.47	2.59	32.27^{c}	0.16	70.98^{ab}	1.81
T6	33.90^{d}	14.87	2.93	32.33^{c}	0.20	73.48^{ab}	1.55
T7	34.73^{bcd}	14.48	2.80	32.43^{bc}	0.18	70.15^{ab}	1.84
T8	41.53^{ab}	11.46	2.56	32.60^{ab}	0.16	74.80^{ab}	1.81
T9	42.13^{a}	12.15	2.69	32.80^{a}	0.16	80.08^{a}	1.58
T10	31.57^{d}	14.18	2.96	32.77^{a}	0.19	67.14^{b}	1.42
SEm±	4.48*	4.09^{ns}	0.50^{ns}	0.27*	0.05^{ns}	6.39*	0.37^{ns}

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.4. Per cent AMF colonization

Analysis of variance revealed significant difference in colonization percentage and total number of spores in the soil due different treatments (Table 27). With regards to colonization percentage, the highest value was (56.33 %) recorded for seedling treated with *G. proliferum* with 50 g inoculum (T9) and the least (0.00 %) colonization

percentage was occurred in seedlings without AMF inoculation kept as control (T10). Meanwhile, highest spore count (137.00) was recorded for seedlings inoculated with *G. proliferum* with 50 g inoculum (T9) and the lowest value (15.00) was observed in seedlings without AMF inoculation kept as control (T10).

Table 27. Per cent AMF and number of AMF spores in *Tectona grandis* as influenced by different treatments at 150 DAI

Treatments	Root colonization (%)	Number of spores/10 g soil
T1	17.33^{f}	24.00^{f}
T2	23.33^{e}	33.00^{e}
T3	28.67^{d}	50.00^{d}
T4	24.00^{de}	37.00^{e}
T5	28.33^{d}	47.67^{d}
T6	22.67^{e}	63.33^{d}
T7	33.33^{c}	90.67^{c}
T8	43.33^{b}	119.00^{b}
T9	56.33^{a}	137.00^{a}
T10	0.00^{g}	15.00^{g}
SEm±	2.68*	7.27*

**Significant at 0.05 levels*
Values with same superscript in column at different month are homogenous

4.1.5. Quality assessment

4.1.5.1. Biovolume index

Analysis of variance revealed significant difference in biovolume index due to different treatments over time. In general, biovolume index at monthly intervals showed an increasing trend (Table 28). At 30 DAI, treatments T1, T3, T5 and T8 were on par. The highest (33.82) biovolume index was observed in *G. intradices* with 50 g inoculum (T6) and least (8.66) for control (T10). At 60 DAI, all except T1 and control (T10) were on par with other treatments. The highest (36.89) biovolume index was observed in *F. mosseae* with 10 g inoculum (T1) and least (16.63) for control (T10). At 90 DAI, treatments T3, T4 and T6 were on par. The highest (74.20) biovolume index was observed in *G. proliferum* with 25 g inoculum (T8) and least (37.87) for *F. mosseae* with 50 g inoculum (T3). At 120 DAI, all except T8 and T9 were on par with other treatments. The highest (699.28) biovolume index was observed in *G. proliferum* with 50 g inoculum (T9) and least (38.67) for *F. mosseae* with 25 g inoculum (T2). At the

end of the study, all except T8 and T9 were on par with other treatments. With regard to biovolume index, the highest value was (818.49) recorded for *G. proliferum* with 50 g inoculum (T9). The least (69.40) biovolume index occurred in seedlings inoculated with *F. mosseae* with 25 g inoculum (T2) at the end of the study.

Table 28. Biovolume index of *Tectona grandis* as influenced by different treatments at monthly intervals

Biovolume index					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	20.75^{b}	36.89^{a}	45.11^{cd}	96.48^{c}	140.11^{c}
T2	17.65^{bc}	26.56^{ab}	47.19^{cd}	38.67^{c}	69.40^{c}
T3	21.04^{b}	23.01^{ab}	37.87^{d}	45.79^{c}	78.83^{c}
T4	9.99^{c}	20.77^{ab}	39.24^{d}	43.47^{c}	75.55^{c}
T5	19.21^{b}	21.35^{ab}	60.15^{abc}	64.37^{c}	102.69^{c}
T6	33.82^{a}	27.79^{ab}	38.31^{d}	46.29^{c}	79.77^{c}
T7	15.70^{bc}	26.40^{ab}	61.86^{abc}	102.04^{c}	149.11^{c}
T8	20.64^{b}	23.02^{ab}	74.20^{a}	393.83^{b}	481.66^{b}
T9	9.02^{c}	23.20^{ab}	68.62^{ab}	699.28^{a}	818.49^{a}
T10	8.66^{c}	16.63^{b}	53.13^{bcd}	42.88^{c}	75.00^{c}
SEm±	1.52*	1.64*	2.74*	39.04*	44.28*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.5.2. Seedling Quality index

Analysis of variance revealed significant difference in seedling quality index due to different treatments over time. Generally, seedling quality index at monthly intervals showed an increasing trend (Table 29). At 30 DAI, all except T3, T4, T6, T9 and control (T10) were on par. The highest (0.19) seedling quality index was observed in *G. intradices* with 50 g inoculum (T6) and least (0.02) seedling quality index observed for control (T10). At 60 DAI, there was no significant variation in seedling quality index due to various treatments. At 90 DAI, treatments T1, T2, T4, T7 and control (T10) were on par. The highest (0.77) seedling quality index was observed in *G. intradices* with 25 g inoculum (T5) and data pertaining to next higher and comparable (0.76) seedling quality index recorded for *G. proliferum* with 50 g inoculum (T9) and *G. proliferum* with 25 g inoculum (T8). The least (0.38) seedling quality index recorded for *F. mosseae* with 50 g inoculum (T3). At 120 DAI, treatments T2, T3, T4 and T6 were on par. The highest (1.17) seedling quality index was observed in *G. proliferum* with 50 g inoculum (T9) and least (0.49) for *G. intradices* with 10 g inoculum (T4). At the end of the study, treatments T2, T3, T5 and T6 were on par with other treatments. A similar

trend was followed in the seedling quality index by next month. With regard to quality index, the highest value was (1.19) recorded for *G. proliferum* with 50 g inoculum (T9). The least (0.74) quality index occurred in seedlings without AMF inoculation kept as control (T10) at the end of the study.

Table 29. Seedling Quality Index of *Tectona grandis* as influenced by different treatments at monthly intervals

Seedling Quality Index					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	0.16^{abc}	0.33	0.55^{ab}	0.80^{abcd}	0.94^{abc}
T2	0.07^{abc}	0.16	0.44^{ab}	0.61^{d}	0.83^{bc}
T3	0.17^{ab}	0.23	0.38^{b}	0.52^{d}	0.76^{bc}
T4	0.05^{bc}	0.33	0.51^{ab}	0.49^{d}	0.74^{c}
T5	0.09^{abc}	0.25	0.77^{a}	0.64^{cd}	0.82^{bc}
T6	0.19^{a}	0.27	0.73^{a}	0.61^{d}	0.82^{bc}
T7	0.08^{abc}	0.25	0.70^{ab}	1.03^{ab}	1.12^{a}
T8	0.16^{abc}	0.20	0.76^{a}	1.00^{abc}	1.04^{ab}
T9	0.04^{bc}	0.25	0.76^{a}	1.17^{a}	1.19^{a}
T10	0.02^{c}	0.20	0.65^{ab}	0.73^{bcd}	0.91^{abc}
SEm±	0.02*	0.03^{ns}	0.04*	0.05*	0.04*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.5.3. Mycorrhizal Efficiency Index

Analysis of variance revealed significant difference in mycorrhizal efficiency index due to different treatments over time. While, mycorrhizal efficiency index at monthly intervals showed an increasing trend (Table 30). At 30 DAI and 60 DAI, there was no significant variation in mycorrhizal efficiency index due to various treatments. At 90 DAI, treatments T1, T6 and control (T10) were on par. The highest (35.57) mycorrhizal efficiency index was observed in *G. proliferum* with 50 g inoculum (T9) and least (-59.69) mycorrhizal efficiency index recorded for *F. mosseae* with 50 g inoculum (T3). At 120 DAI, all except T4, T7, T8 and T9 were on par with other treatments. The highest (92.64) mycorrhizal efficiency index was observed in *G. proliferum* with 50 g inoculum (T9) and least (-133.95) for *G. intradices* with 10 g inoculum (T4). At the end of the study, treatments T2, T3, T4 and T6 were on par. With regard to mycorrhizal efficiency index, the highest value was (89.23) recorded for *G. proliferum* with 50 g inoculum (T9). Similarly, the next lower and comparable (77.67) mycorrhizal efficiency index recorded in seedlings subjected to *G. proliferum* with 25 g

inoculum (T8). The least (-53.68) mycorrhizal efficiency index occurred in seedlings subjected to *G. intradices* with 10 g inoculum (T4) at the end of the study.

Table 30. Mycorrhizal efficiency index of *Tectona grandis* as influenced by different treatments at monthly intervals

Mycorrhizal Efficiency Index					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	57.11	41.83	-3.91^{abcd}	16.86^{ab}	14.07^{abc}
T2	43.19	-8.50	-43.66^{cd}	-40.43^{ab}	-24.02^{c}
T3	61.24	19.74	-59.69^{d}	-58.56^{ab}	-31.16^{c}
T4	-0.25	-7.54	-30.72^{bcd}	-133.95^{b}	-53.68^{c}
T5	58.72	29.74	30.76^{ab}	-6.60^{ab}	-3.26^{bc}
T6	75.34	11.95	-14.83^{abcd}	-43.58^{ab}	-22.27^{c}
T7	40.99	-8.09	11.10^{abc}	32.35^{a}	28.38^{abc}
T8	64.11	16.07	30.25^{ab}	84.02^{a}	77.67^{ab}
T9	25.69	13.23	35.57^{a}	92.64^{a}	89.23^{a}
T10	0.00	0.00	0.00^{abcd}	0.00^{ab}	0.00^{bc}
SEm±	7.77^{ns}	13.06^{ns}	7.58*	17.17*	10.70*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.1.5. Cluster analysis

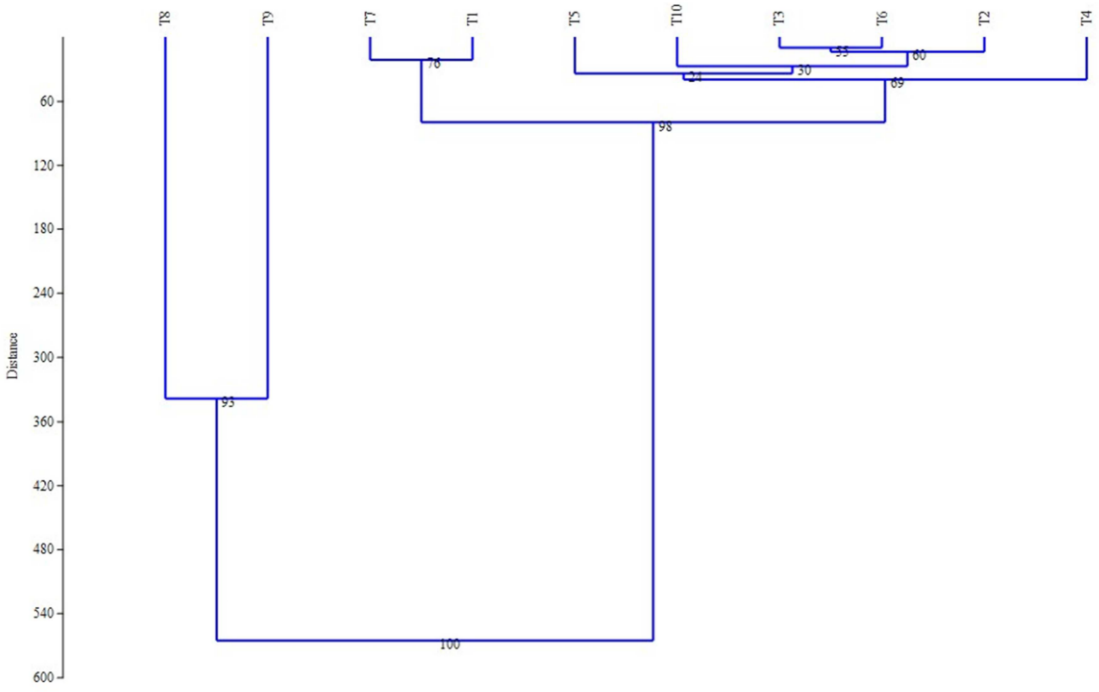


Fig. 2. The dendrogram of the cluster analysis of *Tectona grandis* subjected to different treatments

The dendrogram of the cluster analysis of *Tectona grandis* subjected to different AMF species with various dose of mycorrhiza are presented Figure 1. Cluster analysis identified two clusters. First cluster contained the seedlings subjected to *G. proliferum* with 25 g inoculum (T8) and *G. proliferum* with 50 g inoculum (T9). The second cluster contained the seedlings subjected to *F. mosseae* with 10 g inoculum (T1), *F. mosseae* with 25 g inoculum (T2), *F. mosseae* with 50 g inoculum (T3), *G. intradices* with 10 g inoculum (T4), *G. intradices* with 25 g inoculum (T5), *G. intradices* with 50 g inoculum (T6), *G. proliferum* with 10 g inoculum (T7) and seedlings kept as control (T10).

4.2. MAHOGANY (*Swietenia macrophylla)*

4.2.1. Above-ground parameters

4.2.1.1. Shoot height

Analysis of variance revealed significant differences in seedling height due to different treatments over time. In general, seedling height at monthly intervals showed an increasing trend (Table 31). At 30 DAI, all except control (T10) were on par with different treatments in height. The highest value (20.8 cm) was recorded for seedlings treated with *F. mosseae* with 25 g inoculum (T2) and least (15.5 cm) for control (T10). At 60 DAI, there was no significant variation in seedling height due to various treatments. With regards to seedling height at 90 DAI, all except *G. proliferum* with 25 g inoculum (T8) were on par with each other. The highest (30.5 cm) height was observed in *G. intradices* with 10 g inoculum (T4) and least (19.7 cm) for *G. proliferum* with 25 g inoculum (T8). Data pertaining to 120 DAI, treatments T6, T7, T8, T9 and control (T10) were on par. The tallest (40.2 cm) seedlings were observed in *G. intradices* with 10 g inoculum (T4) and least (22.9 cm) for *G. proliferum* with 25 g inoculum (T8). At 150 DAI, treatments T9, T1, T2 and T3 were on par with each other. Exploration of data at the end of the study indicated that the highest value was (47.7 cm) recorded for *G. intradices* with 10 g inoculum (T4) and *F. mosseae* with 25 g inoculum (T2) (45.7 cm) and the least (22.0 cm) seedling height occurred in seedlings without AMF inoculation kept as control (T10). Greater than 100 per cent increase seedling height was observed in seedlings subjected to *G. intradices* with 10 g inoculums (T4) compared to control.

Table 31. Seedling height (cm) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Seedling height (cm)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	19.3^{ab}	19.5	25.3^{ab}	25.6^{bc}	39.2^{ab}
T2	20.8^{a}	21.9	29.1^{a}	32.6^{b}	45.7^{a}
T3	18.4^{ab}	21.0	29.7^{a}	25.8^{bc}	42.9^{ab}
T4	19.7^{ab}	21.0	30.5^{a}	40.2^{a}	47.7^{a}
T5	17.8^{ab}	23.1	29.1^{a}	28.7^{bc}	29.1^{cd}
T6	18.5^{ab}	27.3	28.6^{ab}	25.0^{c}	28.0^{cd}
T7	18.7^{ab}	21.3	22.6^{ab}	25.1^{c}	26.5^{d}
T8	18.6^{ab}	18.3	19.7^{b}	22.9^{c}	30.4^{cd}
T9	17.0^{ab}	19.7	24.8^{ab}	23.5^{c}	35.5^{bc}
T10	15.5^{b}	17.3	22.5^{ab}	24.9^{c}	22.0^{d}
SEm±	0.46*	1.15^{ns}	0.98*	1.12*	1.70*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.1.2. Collar diameter

Analysis of variance revealed significant differences in seedling collar diameter due to different treatments over time. Generally, seedling collar diameter at monthly intervals showed an increasing trend (Table 32). At 30 DAI, all treatments except T2 significantly differed from control. The highest value (2.80 mm) was recorded for seedlings treated with *G. proliferum* with 50 g inoculum (T9) and least (1.61 mm) for control (T10). At 60 DAI, treatments T2, T3, T4, T6 and T8 were on par. The highest (3.54 mm) collar diameter was observed in *G. proliferum* with 10 g inoculum (T7) and least (2.37 mm) for control (T10). At 90 DAI, the treatments T1, T3, T6, T7, T8 and T9 were on par. The highest (5.03 mm) collar diameter was observed in *G. intradices* with 25 g inoculum (T5) and least (3.07 mm) for control (T10). At 120 DAI, treatments T2, T3, T5, T6, T7, T8 and T9 were on par and differed from control (T10). The highest collar diameter (6.07 mm) was observed in *G. intradices* with 10 g inoculum (T4) and least (2.98 mm) for control (T10). At the end of the study, treatments T3 and T4 were on par and control (T10) were on par with T1, T5, T6, T7 and T8. With regard to collar diameter at the end of the study, the highest (7.55 mm) recorded for *G. intradices* with 10 g inoculum (T4) and least seedling collar diameter (5.18 mm) was occurred in seedlings treated with *G. proliferum* with 10 g inoculum (T7). Greater than 1/3 fold differences in seedling collar diameter were observed in seedlings subjected to *G. intradices* with 10 g inoculums (T4) compared to control.

Table 32. Seedling collar diameter (mm) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Seedling collar diameter (mm)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	2.35^{ab}	2.50^{b}	3.75^{ab}	4.35a^{b}	6.41^{abcd}
T2	2.78^{a}	3.05^{ab}	4.23^{b}	4.50^{b}	6.93^{ab}
T3	2.09^{ab}	2.81^{ab}	3.92^{ab}	3.99^{ab}	7.42^{a}
T4	2.65^{ab}	3.12^{ab}	4.20^{b}	6.07^{a}	7.55^{a}
T5	2.70^{a}	3.53^{a}	5.03^{a}	3.67^{ab}	5.95^{bcd}
T6	2.05^{ab}	2.88^{ab}	3.85^{ab}	4.11^{ab}	5.35^{d}
T7	2.63^{ab}	3.54^{a}	3.75^{ab}	4.24^{ab}	5.18^{d}
T8	2.33^{ab}	2.74^{ab}	3.50^{ab}	3.66^{ab}	5.58^{bcd}
T9	2.53^{ab}	2.59^{b}	3.56^{ab}	3.81^{ab}	6.82^{abc}
T10	1.61^{b}	2.37^{b}	3.07^{c}	3.15^{c}	5.51^{cd}
SEm±	0.10*	0.10*	0.11*	0.17*	0.19*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.1.3. Number of leaves

Analysis of variance revealed significant differences in number of leaves due to different treatments over time. Number of leaves at monthly intervals showed an increasing trend (Table 33). At 30 DAI, all treatments except T3, T5, T6 and control (T10) were on par with each other. The highest value (9.0) was recorded for seedlings treated with *F. mosseae* with 10 g inoculum (T1) and least (5.3) for control (T10). At 60 DAI, all treatments except T2, T5, T6, T7 and control (T10) were on par with each other. The highest (11.0) number of leaves was observed in *G. intradices* with 10 g inoculum (T4). The least number of leaves (7.0) observed for *G. proliferum* with 10 g inoculum (T7) and *F. mosseae* with 10 g inoculum (T1). At 90 DAI, treatments T1, T6, T9 and control (T10) were on par with each other. The highest (14.3) number of leaves was observed in *F. mosseae* with 25 g inoculum (T2) and least (9.7) for *G. proliferum* with 10 g inoculum (T7) and *G. proliferum* with 25 g inoculum (T8). At 120 DAI, there was no significant variation in number of leaves due to various treatments. At the end of the study, all except T8 were on par with each other. With regard to number of leaves at 150 DAI, the highest value was (14.7) recorded for *G. proliferum* with 25 g inoculum (T8) and least (8.0) occurred in seedlings treated with *F. mosseae* with 10 g inoculum (T1).

Table 33. Number of leaves of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Number of leaves					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	9.0^{a}	7.0^{b}	13.0^{ab}	12.0	8.0^{b}
T2	8.0^{ab}	9.0^{ab}	14.3^{a}	12.0	10.7^{ab}
T3	6.0^{bc}	7.3^{b}	11.3^{abc}	11.3	11.7^{ab}
T4	6.7^{abc}	11.0^{a}	12.3^{abc}	12.7	11.7^{ab}
T5	6.3^{bc}	8.7^{ab}	11.7^{abc}	9.7	9.0^{b}
T6	6.3^{bc}	8.3^{ab}	10.3^{bc}	11.7	10.3^{ab}
T7	8.3^{ab}	9.7^{ab}	9.7^{c}	9.0	13.7^{ab}
T8	7.0^{abc}	7.0^{b}	9.7^{c}	11.3	14.7^{a}
T9	7.3^{abc}	7.7^{b}	11.0^{bc}	11.7	11.7^{ab}
T10	5.3^{c}	9.3^{ab}	10.7^{bc}	10.3	8.7^{b}
SEm±	0.27*	0.32*	0.36*	0.43^{ns}	0.58*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.1.4. Leaf area

Analysis of variance revealed significant differences in leaf area per plant due to different treatments over time. With age of seedlings leaf area per plant also increased (Table 34). At 30 DAI, all treatments except T1 were on par. At this stage, the highest value (102.98 cm^2) was recorded for seedlings treated with *G. intradices* with 25 g inoculum (T5) and least (43.71 cm^2) for *F. mosseae* with 10 g inoculum (T1). At 60 DAI, treatments T2, T4, T5, T7 and T8 were on par. The highest (120.09 cm^2) leaf area per plant was observed in *F. mosseae* with 10 g inoculum (T1) and least (53.37 cm^2) for *F. mosseae* with 50 g inoculum (T3). At 90 DAI, treatments T7, T8, T9 and control were on par. The highest (323.68 cm^2) leaf surface area per plant was observed in *F. mosseae* with 25 g inoculum (T2) and least (95.06 cm^2) for *G. proliferum* with 25 g inoculum (T8). At 120 DAI, treatments T1, T2, T3 and T7 were on par. The highest (319.59 cm^2) leaf surface area per plant was observed in *G. intradices* with 10 g inoculum (T4) and least (34.88 cm^2) for *G. intradices* with 50 g inoculum (T6). At the end of the study, treatments T2, T4 and T8 were on par with each other. With regard to leaf area per plant, the highest value was (718.33 cm^2) recorded for *G. proliferum* with 50 g inoculum (T9) and least (120.44 cm^2) leaf area per plant occurred in seedlings without AMF inoculation kept as control (T10). Greater than six times increase leaf area per plant was observed in seedlings subjected to *G. proliferum* with 50 g soil inoculums (T9) soil compared to control.

Table 34. Leaf area per plant (cm^2) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Leaf area (cm^2)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	43.71^{b}	120.09^{a}	252.90^{abc}	257.80^{ab}	269.56^{bc}
T2	71.11^{ab}	103.40^{ab}	323.68^{a}	245.10^{ab}	394.07^{abc}
T3	79.68^{ab}	53.37^{cd}	161.34^{bc}	256.68^{ab}	566.85^{ab}
T4	79.12^{ab}	98.44^{abc}	279.59^{ab}	319.59^{a}	485.52^{abc}
T5	102.98^{a}	79.65^{abcd}	225.10^{abc}	135.55^{bc}	202.75^{bc}
T6	48.55^{ab}	64.53^{bcd}	138.66^{bc}	34.88^{c}	179.31^{c}
T7	57.62^{ab}	109.74^{ab}	108.87^{c}	186.56^{abc}	298.81^{bc}
T8	54.98^{ab}	104.00^{ab}	95.06^{c}	97.28^{bc}	405.91^{abc}
T9	54.37^{ab}	85.14^{abcd}	117.75^{c}	106.71^{bc}	718.33^{a}
T10	50.89^{ab}	46.48^{d}	113.35^{c}	101.67^{bc}	120.44^{c}
SEm±	5.87*	5.51*	19.23*	20.93*	43.95*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.1.5. Fresh weight of shoot

Analysis of variance revealed significant differences in fresh weight of shoot due to different treatments over time. Fresh weight of shoot at monthly intervals showed an increasing trend with age (Table 35). At 30 DAI, all except T4 and control (T10) were on par with other treatments. Treatment T4 differed from T3 and T8. Highest fresh weight of shoot (1.68 g) was recorded for seedlings treated with *G. intradices* with 10 g inoculum (T4) and least (0.79 g) for control (T10). At 60 DAI, there was no significant variation in fresh weight of shoots due to various treatments. The values ranged from 2.45 g to 1.22 g. At 90 DAI, all except T2, T8 and control (T10) were on par with each other. The highest (6.01 g) fresh weight of shoot was observed in *F. mosseae* with 25 g inoculum (T2) and least (2.06 g) for *G. proliferum* with 25 g inoculum (T8). At 120 DAI, treatments T6, T8, T9 and control (T10) were on par with each other. The highest (8.98 g) fresh weight of shoot was observed in *G. intradices* with 10 g inoculum (T4) and least (2.41 g) for control (T10). At the end of the study, treatments T5, T6, T7 and control (T10) were on par. Data pertaining to fresh weight of shoot, the highest value was (12.87 g) recorded for *G. intradices* with 10 g inoculum (T4) next higher and comparable (11.84 g) results were shown by *F. mosseae* with 50 g inoculum (T3). The least (3.83 g) fresh weight of shoot occurred in seedlings without AMF inoculation kept as control (T10). Greater than 200 per cent increase fresh weight of shoot was observed in seedlings subjected to *G. intradices* with 10 g inoculum (T4) compared to control.

Table 35. Fresh weight of shoot (g) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Fresh weight of shoot (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	1.35^{ab}	1.36	3.76^{ab}	3.95^{bc}	8.20^{abc}
T2	1.33^{ab}	2.06	6.01^{a}	6.10^{b}	9.91^{ab}
T3	0.87^{ab}	1.78	4.15^{ab}	4.37^{bc}	11.84^{a}
T4	1.68^{a}	2.45	5.40^{ab}	8.98^{a}	12.87^{a}
T5	1.27^{ab}	2.33	5.23^{ab}	4.01^{bc}	4.89^{c}
T6	1.03^{ab}	1.28	3.37^{ab}	3.51^{c}	4.31^{c}
T7	1.52^{ab}	2.07	2.74^{ab}	4.03^{bc}	4.08^{c}
T8	1.33^{ab}	1.39	2.06^{b}	2.77^{c}	5.35^{bc}
T9	1.24^{ab}	1.45	2.82^{ab}	3.25^{c}	8.33^{abc}
T10	0.79^{b}	1.22	2.14^{b}	2.41^{c}	3.83^{c}
SEm±	0.08*	0.15^{ns}	0.37*	0.40*	0.71*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.1.6. Dry weight of shoots

Analysis of variance revealed significant differences in dry weight of shoots due to different treatments over time. The data indicated that, dry weight of shoot at monthly intervals showed an increasing trend (Table 36). At 30 DAI, there was no significant variation in dry weight of shoots between the treatments. At 60 DAI, all except T5 were on par with other treatments. The highest (1.14 g) dry weight of shoot was observed in *G. intradices* with 25 g inoculum (T5) and least (0.53 g) for *G. intradices* with 50 g inoculum (T6). At 90 DAI, all except control were on par. The highest (1.62 g) dry weight of shoot was observed in *F. mosseae* with 25 g inoculum (T2) and least (0.74 g) for control (T10). At 120 DAI, all except T1, T2, T3, T4 and T7 were on par with each other. The highest (3.13 g) dry weight of shoot was observed in *G. intradices* with 10 g inoculum (T4) and least (0.79 g) for control (T10). At the end of the study T4 had the highest shoot weight and did not differ significantly from T2 and T3. Treatments T5, T6 and T7 and control were on par. Whereas highest dry weight of shoots was (5.35 g) recorded *G. intradices* with 10 g inoculum (T4). The least dry weight of shoots occurred in seedlings without AMF inoculation kept as control (T10) (1.15 g) at the end of the study. Greater than four times increase of dry weight of shoot was observed in seedlings subjected to *G. intradices* with 10 g inoculum (T4) compared to control.

Table 36. Dry weight of shoot (g) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Dry weight of shoot (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	0.46	0.64^{ab}	0.97^{ab}	1.63^{ab}	3.39^{bcd}
T2	0.43	0.98^{ab}	1.62^{a}	2.02^{b}	3.86^{abc}
T3	0.32	0.73^{ab}	0.94^{ab}	1.23^{ab}	4.38^{ab}
T4	0.59	0.90^{ab}	1.51^{ab}	3.13^{a}	5.35^{a}
T5	0.58	1.14^{a}	1.65^{ab}	1.21^{ab}	2.01^{cde}
T6	0.35	0.53^{b}	1.13^{ab}	1.19^{ab}	1.67^{de}
T7	0.53	0.85^{ab}	1.11^{ab}	1.56^{ab}	1.53^{de}
T8	0.51	0.61^{b}	0.76^{ab}	1.14^{ab}	1.98^{cde}
T9	0.46	0.59^{b}	1.03^{ab}	1.10^{ab}	3.33^{bcd}
T10	0.27	0.57^{b}	0.74^{b}	0.79^{c}	1.15^{e}
SEm±	0.03^{ns}	0.05*	0.09*	0.14*	0.29*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.1.7. Fresh weight of leaves

Analysis of variance revealed significant differences in fresh weight of leaves due to different treatments over time. Data pertaining to fresh weight of leaves at monthly intervals showed an increasing trend (Table 37). At 30 DAI, all except T7 and T1 were on par. The highest (2.11 g) fresh weight of leaves was observed in *F. mosseae* with 10 g inoculum (T1) and least (0.79 g) for control (T10). At 60 DAI, there was no significant variation in fresh weight of leaves due to various treatments. At 90 DAI, except T1, T2, T3, T4 and control (T10) were on par with other treatments. The highest (8.97 g) fresh weight of leaves was observed in *G. intradices* with 10 g inoculum (T4) and least (1.82 g) for control (T10). At 120 DAI, except T2, T4, T7, T8 and control (T10) were on par with other treatments. The highest (9.22 g) fresh weight of leaves was observed in *G. intradices* with 10 g inoculum (T4) and least (2.63 g) for control (T10). At the end of the study, treatments T5, T6 and control (T10) were on par. The highest value was (14.59 g) recorded for *G. proliferum* with 50 g inoculum (T9) next higher and comparable fresh weight of leaves were obtained in *G. intradices* with 10 g inoculum (T4) (14.27 g). The least (3.25 g) fresh weight of leaves occurred in seedlings without AMF inoculation kept as control (T10) at this stage. Greater than 3 times increase seedling fresh weight of leaves was observed in seedlings subjected to *G. intradices* with 10 g inoculum (T4) compared to control.

Table 37. Fresh weight of leaves (g) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Fresh weight of leaves (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	2.11^{a}	2.37	3.95^{bc}	7.02^{abc}	8.08^{abc}
T2	1.64^{ab}	2.27	5.75^{b}	9.02^{ab}	10.16^{abc}
T3	0.87^{b}	2.07	3.37^{bcd}	4.34^{abc}	14.27^{a}
T4	1.68^{ab}	2.32	8.97^{a}	9.22^{a}	12.36^{ab}
T5	1.32^{ab}	2.75	3.01^{cd}	6.42^{abc}	5.10^{c}
T6	1.02^{b}	1.35	2.82^{cd}	3.61^{abc}	4.13^{c}
T7	1.93^{a}	2.56	2.96^{cd}	4.03^{abc}	6.10^{bc}
T8	1.68^{ab}	1.98	2.56^{cd}	2.27^{c}	7.95^{abc}
T9	1.39^{ab}	1.53	2.38^{cd}	3.04^{bc}	14.59^{a}
T10	0.79^{b}	1.33	1.82^{d}	2.63^{c}	3.25^{c}
SEm±	0.11*	1.47^{ns}	0.40*	0.66*	0.91*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.1.8. Dry weight of leaves

Analysis of variance revealed significant differences in dry weight of leaves due to different treatments over time. Dry weight of leaves at monthly intervals showed an increasing trend with increasing age (Table 38). At 30 DAI, all except T1, T3, T7 and control (T10) were on par with other treatments. The highest (0.69 g) dry weight of leaves was observed in *G. proliferum* with 10 g inoculum (T7) and least (0.28 g) for control (T10). At 60 DAI, there was no significant variation in dry weight of leaves due to various treatments. At 90 DAI, treatments T5, T6, T7, T8 and T9 were on par. The highest (2.64 g) dry weight of leaves was observed in *G. intradices* with 10 g inoculum (T4) and least (0.73 g) for control (T10). At 120 DAI, treatments T1 and T5 were on par with each other. The highest (3.13 g) dry weight of leaves was observed in *G. intradices* with 10 g inoculum (T4) and least (0.92 g) for control (T10). At the end of the study, treatments T6 and control (T10) were on par. At this stage the highest value was (6.10 g) recorded for *G. proliferum* with 50 g inoculum (T9) consequently by *F. mosseae* with 50 g inoculum (T3) (5.48 g). The least (1.20 g) dry weight of leaves occurred in seedlings without AMF inoculation kept as control (T10) at the end of the study. Greater than fivefold increase dry weight of leaves was observed in seedlings subjected to *G. proliferum* with 50 g soil inoculum compared to control.

Table 38. Dry weight of leaves (g) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Dry weight of leaves (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	0.64^{ab}	0.67	1.63^{abc}	2.04^{abc}	2.92^{bcd}
T2	0.56^{abc}	0.99	2.02^{ab}	2.71^{ab}	3.89^{abcd}
T3	0.31^{bc}	0.82	1.23^{bc}	1.34^{c}	5.48^{ab}
T4	0.62^{abc}	0.98	2.64^{a}	3.13^{a}	4.98^{abc}
T5	0.57^{abc}	1.16	1.21^{bc}	2.06^{abc}	2.09^{cd}
T6	0.35^{abc}	0.60	1.07^{bc}	1.26^{ab}	1.59^{d}
T7	0.69^{a}	0.89	1.06^{bc}	1.56^{bc}	2.42^{cd}
T8	0.58^{abc}	0.61	0.90^{bc}	1.14^{bc}	3.21^{bcd}
T9	0.53^{abc}	0.60	0.97^{bc}	1.20^{c}	6.10^{a}
T10	0.28^{c}	0.58	0.73^{c}	0.92^{c}	1.20^{d}
SEm±	0.04*	0.06^{ns}	0.14*	0.16*	0.38*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.2. Below-ground parameters

4.2.2.1. Tap root length

Analysis of variance revealed significant differences in tap root length due to different treatments over time. While, tap root length at monthly intervals showed an increasing trend (Table 39). At 30 DAI, there was no significant variation in tap root length due to various treatments. At 60 DAI, all except treatments T1, T2, T6 and T9 were on par. The highest (20.67 cm) tap root length was observed in *F. mosseae* with 10 g inoculum (T1) and least (14.67 cm) for *G. intradices* with 50 g inoculum (T6). At 90 DAI, there was no significant variation in tap root length due to various treatments. At 120 DAI, treatments T3, T5, T8 and T9 were on par with other treatments. The highest (31.00 cm) tap root length was observed in *G. proliferum* with 10 g inoculum (T7) and least (17.43 cm) for control (T10). At the end of the study, treatments T1, T4 and T9 were on par. The longest root was (31.33 cm) recorded for *G. proliferum* with 25 g inoculum (T8) and least (21.00 cm) occurred in seedlings without AMF inoculation kept as control (T10) at the end of the study. Greater than 1/3 times increase tap root length was observed in seedlings subjected to *G. proliferum* with 25 g inoculum compared to control.

Table 39. Tap root length (cm) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Tap root length (cm)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	14.93	20.67^{a}	14.07	23.67^{abc}	24.66^{bcd}
T2	18.07	20.33^{ab}	16.80	25.80^{ab}	26.53^{abc}
T3	13.80	16.67^{abc}	15.23	22.13^{bc}	26.67^{abc}
T4	16.23	15.33^{abc}	16.23	24.33^{abc}	24.00^{bcd}
T5	15.67	18.67^{abc}	13.30	20.63^{bc}	20.03^{d}
T6	13.13	14.67^{c}	14.80	26.00^{ab}	25.66^{bc}
T7	17.90	15.33^{abc}	15.30	31.00^{a}	29.66^{ab}
T8	17.20	17.67^{abc}	14.90	20.00^{bc}	31.33^{a}
T9	14.87	15.00^{bc}	18.03	22.63^{bc}	25.20^{bcd}
T10	14.00	16.00^{abc}	13.33	17.43^{c}	21.00^{cd}
SEm±	0.59^{ns}	0.58*	0.48^{ns}	0.93*	0.80*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.2.2. Number of lateral roots

Analysis of variance revealed significant differences in number of lateral roots due to different treatments over time. In, number of lateral roots at monthly intervals showed an increasing trend (Table 40). At 30 DAI, all except T1 and control (T10) were on par with other treatments. The highest (44.67) number of lateral roots was observed in *F. mosseae* with 10 g inoculum (T1) and least (19.33) for control (T10). At 60 DAI, treatments T2, T4, T6, T8 and control (T10) were on par. The highest (36.67) number of lateral roots was observed in *G. proliferum* with 10 g inoculum (T7) and least (19.67) for *G. proliferum* with 50 g inoculum (T9). At 90 DAI, there was no significant variation in number of lateral roots between the treatments. At 120 DAI, treatments T2, T3 and T7 were on par. The highest (51.67) number of lateral roots was observed in *F. mosseae* with 10 g inoculum (T1) and least (22.33) for control (T10). At the end of the study, all except treatments T3, T5, T6 and control (T10) were on par with other treatments. With regard to number of lateral roots, the highest value was (50.00) recorded for *F. mosseae* with 50 g inoculum (T3). The least (23.33) number of lateral roots occurred in seedlings without AMF inoculation kept as control (T10) at the end of the study. Greater than 100 per cent increase number of lateral roots was observed in seedlings subjected to *F. mosseae* with 50 g soil inoculum (T3) compared to control.

Table 40. Number of lateral roots of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Number of lateral roots					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	44.67^{a}	33.00^{ab}	35.00	51.67^{a}	35.00^{b}
T2	38.00^{ab}	25.67^{abc}	34.00	48.00^{ab}	39.00^{b}
T3	25.00^{ab}	22.67^{bc}	33.67	44.00^{ab}	50.00^{a}
T4	34.67^{ab}	30.33^{abc}	38.67	51.00^{a}	33.00^{b}
T5	34.00^{ab}	32.00^{ab}	38.33	35.00^{bcd}	23.33^{c}
T6	27.33^{ab}	28.00^{abc}	35.33	28.33^{cd}	29.67^{bc}
T7	35.33^{ab}	36.67^{a}	31.67	47.33^{ab}	33.67^{b}
T8	37.33^{ab}	30.33^{abc}	28.00	37.33^{abc}	39.00^{b}
T9	38.67^{ab}	19.67^{c}	30.67	38.67^{abc}	37.67^{b}
T10	19.33^{b}	30.00^{abc}	30.33	22.33^{d}	23.33^{c}
SEm±	2.06*	1.26*	1.04^{ns}	2.10*	1.60*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.2.3. Fresh weight of roots

Analysis of variance revealed significant differences in fresh weight of roots due to different treatments over time. Data pertaining to fresh weight of roots at monthly intervals showed an increasing trend (Table 41). At 30 DAI, treatments T2, T4, T7 and T8 were on par with other treatments. The highest (2.03 g) fresh weight of roots was observed in *F. mosseae* with 10 g inoculum (T1) and least (0.68 g) for control (T10). At 60 DAI, all except treatments T4, T6 and T7 were on par with other treatments. The highest (4.61 g) fresh weight of roots was observed in *G. proliferum* with 10 g inoculum (T7) and least (1.63) for *G. intradices* with 50 g inoculum (T6). At 90 DAI, all except T2, T5 and control (T10) were on par with other treatments. The highest (7.63 g) fresh weight of roots was observed in *F. mosseae* with 25 g inoculum (T2) and least (3.32 g) for control (T10). At 120 DAI, treatments T1, T3, T6 and T7 were on par. The highest (7.54 g) fresh weight of roots was observed in *G. intradices* with 10 g inoculum (T4) and least (3.77 g) for control (T10). At the end of the study, treatments T1, T2, T4, T6 and T9 were on par. With regard to fresh weight of roots, the highest value was (9.76 g) recorded for *F. mosseae* with 50 g inoculum (T3) lower and comparable fresh weight of roots (7.99 g) by *G. intradices* with 10 g inoculum (T4) and *G. proliferum* with 50 g inoculum (T9) (7.99 g). The least fresh weight of roots occurred in seedlings subjected to *G. proliferum* with 10 g inoculum T10 (5.85 g) at the end of the study.

Table 41. Fresh weight of roots (g) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Fresh weight of roots (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	2.03^{a}	2.27^{bc}	6.15^{ab}	6.83^{ab}	7.03^{ab}
T2	1.66^{ab}	2.83^{bc}	7.63^{a}	7.54^{a}	6.86^{ab}
T3	0.81^{cd}	2.26^{bc}	5.46^{ab}	6.36^{ab}	9.76^{a}
T4	1.68^{ab}	3.08^{b}	6.88^{ab}	7.87^{a}	7.99^{ab}
T5	1.19^{abcd}	2.93^{bc}	3.25^{b}	3.88^{b}	5.87^{b}
T6	1.04^{bcd}	1.63^{c}	5.47^{ab}	5.04^{ab}	6.50^{ab}
T7	1.87^{ab}	4.61^{a}	4.96^{ab}	6.39^{ab}	5.53^{b}
T8	1.72^{ab}	2.21^{bc}	4.69^{ab}	4.81^{bc}	5.63^{b}
T9	1.56^{abc}	1.85^{bc}	4.62^{ab}	4.96^{abc}	7.99^{ab}
T10	0.68^{d}	1.68^{bc}	3.32^{b}	3.77^{b}	5.85^{b}
SEm±	0.11*	0.19*	0.38*	0.70*	0.38*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.2.4. Dry weight of roots

Analysis of variance revealed significant differences in dry weight of roots due to different treatments over time. Generally, dry weight of roots at monthly intervals showed an increasing trend (Table 42). At 30 DAI, all treatments except T3, T4, T6 and T7 were on par with other treatments. The highest (0.57 g) dry weight of roots was observed in *G. intradices* with 10 g inoculum (T4) and least (0.21 g) for *F. mosseae* with 50 g inoculum (T3). At 60 DAI, all treatments except T4, T5 and T7 were on par. The highest (1.13 g) dry weight of roots was observed in *G. intradices* with 25 g inoculum (T5) and least (0.56 g) for *G. proliferum* with 50 g inoculum (T9). At 90 DAI, there was no significant variation in dry weight of roots between treatments. At 120 DAI, all treatments except T4 and control (T10) were on par. The highest (2.35 g) dry weight of roots was observed in *G. intradices* with 10 g inoculum (T4) and least (1.01 g) for control (T10). At the end of the study, treatments T1, T2, T8 and control (T10) were on par. A similar trend was observed in next month. With regard to dry weight of roots, the highest value was (3.35 g) recorded for *G. intradices* with 10 g inoculum (T4) and *G. proliferum* with 50 g inoculum (T9). Next lower and comparable (3.33 g) dry weight was observed in *G. intradices* with 10 g inoculum (T4). The least (1.79 g) dry weight of roots occurred in seedlings subjected to *G. intradices* with 50 g inoculum (T6) at the end of the study.

Table 42. Dry weight of roots (g) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Dry weight of roots (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	0.39^{abc}	0.68^{b}	1.45	2.03^{ab}	3.00^{ab}
T2	0.36^{abc}	0.95^{ab}	1.80	2.08^{ab}	3.00^{ab}
T3	0.21^{c}	0.64^{b}	1.21	1.66^{ab}	3.35^{a}
T4	0.57^{a}	0.84^{ab}	1.61	2.35^{a}	3.33^{a}
T5	0.43^{abc}	1.13^{a}	1.30	1.37^{ab}	1.85^{b}
T6	0.25^{bc}	0.55^{b}	1.23	1.27^{ab}	1.79^{b}
T7	0.55^{ab}	1.10^{a}	1.40	2.02^{ab}	1.85^{b}
T8	0.42^{abc}	0.61^{b}	1.08	1.37^{ab}	2.29^{ab}
T9	0.42^{abc}	0.56^{b}	1.37	1.64^{ab}	3.35^{a}
T10	0.37^{abc}	0.57^{b}	0.96	1.01^{b}	2.09^{ab}
SEm±	0.03*	0.05*	0.09^{ns}	0.11*	0.16*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.2.5. Total fresh weight

Analysis of variance revealed significant differences in total fresh weight due to different treatments over time at five per cent level. Meanwhile, total fresh weight at monthly intervals showed an increasing trend (Table 43). At 30 DAI, treatments T2 and T8 were on par. The highest (5.64 g) total fresh weight was observed in *G. intradices* with 10 g inoculum (T4) and least (2.26 g) for control (T10). At 60 DAI, treatments T1, T8 and T9 were on par. The highest (9.24 g) total fresh weight was observed in *G. proliferum* with 10 g inoculum (T7) and least (4.24 g) for control (T10). At 90 DAI, all treatments except T2, T4, T8 and control (T10) were on par. The highest (22.67 g) total fresh weight was observed in *F. mosseae* with 25 g inoculum (T2) and least (8.09 g) for control (T10). At 120 DAI, treatments T1, T5 and T9 were on par. The highest (25.82 g) total fresh weight was observed in *G. intradices* with 10 g inoculum (T4) and least (11.04 g) for control (T10). At the end of the study, treatments T6 and T7 were on par. With regard to total fresh weight, the highest value was (35.87 g) recorded for *F. mosseae* with 50 g inoculum (T3) next higher and comparable (33.23 g) total fresh weight was recorded in the seedling subjected to *G. intradices* with 10 g inoculum (T4). The least total fresh weight (12.93 g) occurred in seedlings without AMF inoculation kept as control (T10) at the end of the study. Greater than threefold increase total fresh weight was observed in seedlings subjected to *G. intradices* with 10 g inoculum compared to control.

Table 43. Total fresh weight (g) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Total fresh weight (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	5.64^{a}	5.02^{bc}	16.93^{abc}	18.74^{ab}	23.31^{bcde}
T2	4.63^{abc}	7.16^{abc}	22.67^{a}	16.86^{b}	26.93^{abcd}
T3	2.55^{cd}	6.11^{abc}	13.95^{abc}	11.96^{bcd}	35.87^{a}
T4	5.04^{ab}	7.85^{ab}	21.50^{ab}	25.82^{a}	33.23^{ab}
T5	3.77^{abcd}	8.01^{ab}	18.90^{abc}	19.24^{ab}	25.86^{bcd}
T6	3.09^{bcd}	4.25^{c}	12.46^{abc}	12.80^{bcd}	14.94^{de}
T7	5.33^{ab}	9.24^{a}	10.40^{abc}	14.45^{bc}	15.72^{de}
T8	4.80^{abc}	4.96^{bc}	9.31^{bc}	9.81^{cd}	18.92^{cde}
T9	4.19^{abcd}	4.83^{bc}	10.48^{abc}	19.73^{ab}	30.91^{abc}
T10	2.26^{d}	4.24^{c}	8.09^{c}	11.04^{bcd}	12.93^{e}
SEm±	0.28*	0.42*	1.34*	1.12*	1.79*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.2.6. Total dry weight

Analysis of variance revealed significant differences in total dry weight due to different treatments over time. Whereas, total dry weight at monthly intervals showed an increasing trend (Table 44). At 30 DAI, all treatments except T3, T4 and T7 were on par with each other. The highest (1.78 g) total dry weight was observed in *G. intradices* with 10 g inoculum (T4) and least (0.84 g) for *F. mosseae* with 25 g inoculum (T2). At 60 DAI, treatments T2, T3, T4 and T7 were on par. The highest (3.43 g) total dry weight was observed in *G. intradices* with 25 g inoculum (T5) and least (1.68 g) for *G. intradices* with 50 g inoculum (T6). At 90 DAI, all except T2, T8 and control (T10) were on par with each other. The highest (6.14 g) total dry weight was observed in *F. mosseae* with 25 g inoculum (T2) and least (2.62 g) for control (T10). At 120 DAI, all except T1, T2, T4 and control (T10) were on par with other treatments. The highest (8.60 g) total dry weight was observed in *G. intradices* with 10 g inoculum (T4) and least (3.47 g) for control (T10). At the end of the study, treatments T5, T6 and T7 were on par. Exploration of data indicated that total dry weight was highest (13.66 g) recorded for *G. intradices* with 10 g inoculum (T4) next lower and comparable total dry weight (13.21 g) was recorded for the seedlings subjected to *F. mosseae* with 50 g inoculum (T3). The least total dry weight occurred in seedlings without AMF inoculation kept as control (T10) (4.43 g) at the end of the study. Greater than three

times increase total dry weight was observed in seedlings subjected to *G. intradices* with 10 g inoculum compared to control.

Table 44. Total dry weight (g) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Total dry weight (g)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	1.48^{ab}	1.99^{b}	4.46^{ab}	5.29^{bc}	9.31^{abc}
T2	1.35^{ab}	2.92^{ab}	6.14^{a}	6.82^{b}	10.75^{ab}
T3	0.84^{b}	2.19^{ab}	3.49^{ab}	4.12^{bcd}	13.21^{a}
T4	1.78^{a}	2.73^{ab}	5.77^{ab}	8.60^{a}	13.66^{a}
T5	1.59^{ab}	3.43^{a}	5.35^{ab}	5.79^{bcd}	5.96^{cd}
T6	0.95^{ab}	1.68^{b}	3.70^{ab}	4.41^{bcd}	5.04^{cd}
T7	1.77^{a}	2.84^{ab}	3.57^{ab}	5.13^{bcd}	5.79^{cd}
T8	1.52^{ab}	1.84^{b}	2.74^{b}	3.65^{bcd}	7.48^{bcd}
T9	1.40^{ab}	1.75^{b}	3.29^{ab}	3.58^{bcd}	12.78^{a}
T10	0.92^{ab}	1.71^{b}	2.62^{b}	3.47^{d}	4.43^{d}
SEm±	0.09*	0.15*	0.33*	0.37*	0.74*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.2.7. Shoot-root length ratio

Analysis of variance revealed significant differences in shoot-root length ratio due to different treatments over time. Generally, shoot-root length ratio at monthly intervals showed an increasing trend with few exceptions (Table 45). At 30 DAI, there was no significant variation in shoot-root length ratio due to various treatments. At 60 DAI, all treatments except T1 and T6 were on par with other treatments. The highest (1.81) shoot-root length ratio was observed in *G. intradices* with 50 g inoculum (T6) and least (0.88) for *F. mosseae* with 10 g inoculum (T1). At 90 DAI, all treatments except T5, T7, T8 and T9 were on par. The highest (2.23) shoot-root length ratio was observed in *G. intradices* with 50 g inoculum (T5) and least (1.34) for *G. proliferum* with 25 g inoculum (T8). At 120 DAI, treatments T2, T3, T5 and T8 were on par. The highest (1.71) shoot-root length ratio was observed in *G. intradices* with 10 g inoculum (T4) and least (0.85) for *G. proliferum* with 10 g inoculum (T7). At the end of the study, treatments T1 and T5 were on par. With regard to shoot-root length ratio, the highest value was (2.20) recorded for *G. intradices* with 10 g inoculum (T4) followed by *F. mosseae* with 25 g inoculum (T2) (1.95). The least shoot-root length ratio occurred in seedlings subjected to *G. proliferum* with 10 g inoculum (10 g inoculum and 25 g inoculum (25 g inoculum) T7 and T8 respectively (0.99) at the end of the study. Greater

than 200 per cent increase shoot-root length ratio was observed in seedlings subjected to *G. intradices* with 10 g inoculum compared to control.

Table 45. Shoot-root length ratio of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Shoot-root length ratio					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	1.38	0.88^{b}	1.80^{ab}	1.08^{bc}	1.68^{bc}
T2	1.33	1.06^{ab}	1.76^{ab}	1.28^{abc}	1.95^{ab}
T3	1.34	1.27^{ab}	1.96^{ab}	1.17^{abc}	1.62^{bcd}
T4	1.22	1.36^{ab}	1.92^{ab}	1.71^{a}	2.20^{a}
T5	1.15	1.26^{ab}	2.23^{a}	1.28^{abc}	1.80^{bc}
T6	1.43	1.81^{a}	1.94^{ab}	0.96^{bc}	1.24^{def}
T7	1.07	1.40^{ab}	1.48^{b}	0.85^{c}	0.99^{f}
T8	1.18	1.10^{ab}	1.34^{b}	1.16^{abc}	0.99^{f}
T9	1.15	1.35^{ab}	1.46^{b}	0.98^{bc}	1.41^{cde}
T10	1.18	1.10^{ab}	1.69^{ab}	1.57^{ab}	1.05^{ef}
SEm±	0.06^{ns}	0.08*	0.08*	0.07*	0.08*

**Significant at 0.05 levels*
Values with same superscript in column at different month are homogenous

4.2.2.8. Shoot-root biomass ratio

Analysis of variance revealed significant differences in shoot-root biomass ratio due to different treatments over time. Similarly, shoot-root biomass ratio at monthly intervals showed an increasing trend with few exceptions (Table 46). At 30 DAI, treatments T1, T2, T3, T5 and T6 were on par. The highest (3.20) shoot-root biomass ratio was observed in *F. mosseae* with 50 g inoculum (T3) and least (1.47) for control (T10). At 60 DAI, all treatments except T3 and T7 were on par. The highest (2.40) shoot-root biomass ratio was observed in *F. mosseae* with 50 g inoculum (T3) and least (1.58) for *G. proliferum* with 10 g inoculum (T7). At 90 DAI, there was no significant variation in shoot-root biomass ratio due to various treatments. At 120 DAI, treatments T1, T3, T6, T7, T8 and control (T10) were on par. The highest (2.73) shoot-root biomass ratio was observed in *G. intradices* with 10 g inoculum (T4) and least (1.19) for *G. proliferum* with 50 g inoculum (T9). At the end of the study, all except treatments T3, T4, T9 and control (T10) were on par with other treatments. With regard to shoot-root biomass ratio, the highest value was (3.22) recorded for *G. proliferum* with 50 g inoculum (T9) lower and comparable *G. intradices* with 10 g inoculum (T4) (3.01). The least shoot-root biomass ratio occurred in seedlings without AMF inoculation kept as control (T10) (1.16) at the end of the study. Greater than 250 per cent increase shoot-

root biomass ratio was observed in seedlings subjected to *G. intradices* with 10 g inoculum compared to control.

Table 46. Shoot-root biomass ratio of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Shoot-root biomass ratio					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	2.85^{a}	1.91^{ab}	2.19	1.58^{bc}	2.21^{ab}
T2	2.74^{a}	2.05^{ab}	2.41	1.96^{b}	2.54^{ab}
T3	3.20^{a}	2.40^{a}	2.13	1.51^{bc}	2.94^{a}
T4	2.41^{ab}	2.27^{ab}	2.49	2.73^{a}	3.01^{a}
T5	2.69^{a}	2.07^{ab}	2.24	1.78^{b}	2.12^{ab}
T6	2.87^{a}	2.12^{ab}	1.85	1.68^{bc}	1.85^{ab}
T7	2.36^{ab}	1.58^{b}	1.63	1.59^{bc}	2.06^{ab}
T8	2.59^{ab}	1.98^{ab}	1.62	1.69^{bc}	2.51^{ab}
T9	2.36^{ab}	2.15^{ab}	1.72	1.19^{c}	3.22^{a}
T10	1.47^{b}	1.99^{ab}	1.81	1.64^{bc}	1.16^{b}
SEm±	0.12*	0.07*	0.10^{ns}	0.08*	0.18*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.2.9. Vigour Index I

Analysis of variance revealed significant differences in vigour index I due to different treatments over time. In general, vigour index I at monthly intervals showed an increasing trend (Table 47). At 30 DAI, treatments T4, T7 and T8 were on par. The highest (32.13) vigour index I was observed in *F. mosseae* with 25 g inoculum (T2) and least (24.32) for control (T10). At 60 DAI, there was no significant variation in vigour index I between treatments. At 90 DAI, all except T4 and T8 were on par with other treatments. The highest (38.50) vigour index I was observed in *G. intradices* with 10 g inoculum (T4) and least (28.46) for *G. proliferum* with 25 g inoculum (T8). At 120 DAI, treatments T1, T3, T5 and T6 were on par. The highest (53.16) vigour index I was observed in *G. intradices* with 10 g inoculum (T4) and least (34.85) for control (T10). At the end of the study, treatment T2, T3 and T4 were on par. A similar trend was followed in next month vigour index I. With regard to vigour index I, the highest value was (57.30) recorded for *F. mosseae* with 50 g inoculum (T3). Exploration of data indicated that the next higher and comparable vigour index I recorded in the seedlings subjected to *F. mosseae* with 25 g inoculum (T2) (45.67) and *G. intradices* with 10 g inoculum (T4) (57.11). The least vigour index I occurred in seedlings without AMF inoculation kept as control (T10) (35.40) at the end of the study. Greater than 3/2 fold

increase vigour index I was observed in seedlings subjected to *F. mosseae* with 50 g soil inoculum compared to control.

Table 47. Vigour Index I of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Vigour Index I					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	28.21^{abc}	31.67	32.41^{ab}	40.53^{bcd}	51.51^{ab}
T2	32.13^{a}	33.78	37.76^{ab}	48.05^{ab}	56.78^{a}
T3	26.54^{bc}	30.98	37.02^{ab}	39.49^{bcd}	57.30^{a}
T4	29.55^{ab}	29.94	38.50^{a}	53.16^{a}	57.11^{a}
T5	27.55^{abc}	34.36	34.88^{ab}	38.59^{bcd}	37.40^{cd}
T6	26.04^{bc}	34.58	35.71^{ab}	41.99^{bcd}	41.99^{cd}
T7	30.16^{ab}	30.19	31.20^{ab}	46.19^{abc}	44.16^{bc}
T8	30.52^{ab}	30.05	28.46^{b}	35.32^{d}	50.80^{ab}
T9	26.23^{bc}	28.54	35.27^{ab}	36.86^{cd}	50.00^{ab}
T10	24.32^{c}	27.44	29.50^{ab}	34.85^{d}	35.40^{d}
SEm±	0.59*	1.02^{ns}	0.97*	1.30*	1.57*

**Significant at 0.05 levels*
Values with same superscript in column at different month are homogenous

4.2.2.10. Vigour Index II

Analysis of variance revealed significant differences in vigour index II due to different treatments over time. Similarly, vigour index II at monthly intervals showed an increasing trend (Table 48). At 30 DAI, all except T3, T4 and T7 were on par. The highest (1.46) vigour index II was observed in *G. proliferum* with 10 g inoculum (T7) and least (0.69) for *F. mosseae* with 50 g inoculum (T3). At 60 DAI, treatments T1, T3, T6, T8, T9 including control (T10) were on par. The highest (2.82) vigour index II was observed in *G. intradices* with 25 g inoculum (T5) and least (1.41) for control (T10). At 90 DAI, all except treatments T2, T8 and control (T10) were on par. The highest (5.05) vigour index II was observed in *F. mosseae* with 25 g inoculum (T2) and least (2.16) for control (T10). At 120 DAI, treatments T3, T5, T8 and T9 were on par. The highest (7.08) vigour index II was observed in *G. intradices* with 10 g inoculum (T4) and least (2.03) for control (T10). At the end of the study, treatments T5, T6 and T7 were on par. With regard to vigour index II, the highest value was (11.25) recorded for *G. intradices* with 10 g inoculum (T4) Thereafter by *F. mosseae* with 50 g inoculum (T3) (10.88) and *G. proliferum* with 50 g inoculum (T9) (10.52). The least vigour index II occurred in seedlings without AMF inoculation kept as control (T10) (3.65) at the end of the study.

Greater than threefold increase vigour index II was observed in seedlings subjected to *G. intradices* with 10 g inoculum compared to control.

Table 48. Vigour Index II of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Vigour Index II					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	1.22^{ab}	1.64^{b}	3.68^{ab}	4.35^{bc}	7.67^{abc}
T2	1.11^{ab}	2.40^{ab}	5.05^{a}	5.03^{b}	8.85^{ab}
T3	0.69^{b}	1.81^{b}	2.87^{ab}	3.39^{bcd}	10.88^{a}
T4	1.47^{a}	2.25^{ab}	4.75^{ab}	7.08^{a}	11.25^{a}
T5	1.31^{ab}	2.82^{a}	4.40^{ab}	3.12^{bcd}	4.91^{cd}
T6	0.78^{ab}	1.38^{b}	3.05^{ab}	2.81^{cd}	4.15^{cd}
T7	1.46^{a}	2.34^{ab}	2.94^{ab}	4.22^{bc}	4.77^{cd}
T8	1.25^{ab}	1.51^{b}	2.26^{b}	3.00^{bcd}	6.16^{bcd}
T9	1.15^{ab}	1.44^{b}	2.96^{ab}	2.95^{bcd}	10.52^{a}
T10	0.76^{ab}	1.41^{b}	2.16^{b}	2.03^{d}	3.65^{d}
SEm±	0.08*	0.13*	0.27*	0.31*	0.61*

**Significant at 0.05 levels*
Values with same superscript in column at different month are homogenous

4.2.3. Physiological observations

4.2.3.1. Leaf Area Ratio

Analysis of variance revealed significant differences in leaf area ratio due to different treatments over time. However, leaf area ratio at monthly intervals showed a decreasing trend (Table 49). At 30 DAI, there was no significant variation in leaf area ratio due to various treatments. At 60 DAI, all except T3 differed from T1 and T7 while others were on par. The highest (34.68 cm^2g^{-1}) leaf area ratio was observed in *F. mosseae* with 50 g inoculum (T3) and least (19.95 cm^2g^{-1}) for *G. proliferum* with 10 g inoculum (T7). At 90 DAI, treatments T3, T4, T5 and control (T10) were on par. The highest (57.52 cm^2g^{-1}) leaf area ratio was observed in *F. mosseae* with 10 g inoculum (T1) and least (31.05 cm^2g^{-1}) for *G. proliferum* with 10 g inoculum (T7). At 120 DAI, treatments T7, T8 and T9 were on par. The highest (61.04 cm^2g^{-1}) leaf area ratio was observed in *F. mosseae* with 50 g inoculum (T3) and least (11.43 cm^2g^{-1}) for *G. intradices* with 50 g inoculum (T6). At the end of the study, all except T9 and control (T10) were on par with other treatments. With regard to leaf area ratio, the highest value was (55.99 cm^2g^{-1}) recorded for *G. proliferum* with 50 g inoculum (T9) and least leaf

area ratio occurred in seedlings subjected to control (T10) (26.64 cm^2g^{-1}) at the end of the study.

Table 49. Leaf Area Ratio (cm^2g^{-1}) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Leaf Area Ratio (cm^2g^{-1})					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	84.75	22.12^{b}	57.52^{a}	51.94^{ab}	29.90^{ab}
T2	85.76	23.03^{ab}	54.37^{ab}	40.21^{ab}	36.13^{ab}
T3	63.48	34.68^{a}	45.40^{abc}	61.04^{a}	43.29^{ab}
T4	61.07	28.22^{ab}	46.80^{abc}	36.98^{abc}	34.40^{ab}
T5	78.26	30.16^{ab}	43.35^{abc}	36.43^{abc}	31.45^{ab}
T6	78.75	29.43^{ab}	37.38^{bc}	11.40^{c}	35.46^{ab}
T7	62.91	19.95^{b}	31.05^{c}	34.24^{bc}	46.18^{ab}
T8	69.65	29.85^{ab}	35.20^{bc}	25.91^{bc}	51.94^{ab}
T9	70.66	27.88^{ab}	33.03^{c}	28.79^{bc}	55.99^{a}
T10	55.48	28.99^{ab}	44.43^{abc}	35.85^{abc}	26.64^{b}
SEm±	6.17^{ns}	1.22*	2.16*	3.17*	2.74*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.3.2. Leaf Weight Ratio

Analysis of variance revealed significant differences in leaf weight ratio due to different treatments over time. In general, leaf weight ratio at monthly intervals showed a decreasing trend with few exceptions (Table 50). At 30 DAI, all except treatments T1, T2 and control (T10) were on par with other treatments. The highest (0.43 cm^2g^{-1}) leaf area ratio was observed in *F. mosseae* with 10 g inoculum (T1) and least (0.28 cm^2g^{-1}) for control (T10). At 60 DAI, there was no significant variation in leaf weight ratio due to various treatments. At 90 DAI, treatments T6, T8 and T9 were on par. The highest (0.46 cm^2g^{-1}) leaf area ratio was observed in *F. mosseae* with 10 g inoculum (T1) and least (0.30 cm^2g^{-1}) for *G. proliferum* with 10 g inoculum (T7). At 120 DAI, all except treatments T1, T3, T4 and T9 were on par. The highest (0.36 cm^2g^{-1}) leaf area ratio was observed in *G. intradices* with 10 g inoculum (T4) and least (0.27 cm^2g^{-1}) for *G. proliferum* with 50 g inoculum (T9). At the end of the study, all treatment except T9 and control (T10) were on par with other treatments. With regard to leaf weight ratio, the highest value was (0.47 cm^2g^{-1}) recorded for *G. proliferum* with 50 g inoculum (T9). The least leaf weight ratio occurred in seedlings without AMF inoculation kept as control (T10) (0.27 cm^2g^{-1}) at the end of the study.

Table 50. Leaf Weight Ratio (cm^2g^{-1}) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Leaf Weight Ratio (cm^2g^{-1})					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	0.43^{a}	0.33	0.46^{a}	0.30^{bc}	0.32^{ab}
T2	0.41^{a}	0.33	0.45^{a}	0.33^{b}	0.36^{ab}
T3	0.37^{ab}	0.38	0.38^{abc}	0.30^{bc}	0.42^{ab}
T4	0.37^{ab}	0.36	0.43^{a}	0.36^{a}	0.35^{ab}
T5	0.37^{ab}	0.33	0.38^{abc}	0.32^{b}	0.32^{ab}
T6	0.38^{ab}	0.36	0.34^{bc}	0.31^{b}	0.32^{ab}
T7	0.39^{ab}	0.31	0.30^{c}	0.31^{b}	0.39^{ab}
T8	0.38^{ab}	0.33	0.34^{bc}	0.31^{b}	0.42^{ab}
T9	0.37^{ab}	0.33	0.34^{bc}	0.27^{c}	0.47^{a}
T10	0.28^{b}	0.34	0.36^{abc}	0.31^{b}	0.27^{b}
SEm±	0.01*	0.01^{ns}	0.01*	0.01*	0.02*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.3.3. Specific Leaf Area

Analysis of variance revealed significant differences in specific leaf area due to different treatments over time. In general, specific leaf area at monthly intervals showed a decreasing trend with few exceptions (Table 51). At 30 DAI, 60 DAI, 90 DAI and 150 DAI, there was no significant variation in specific leaf area due to various treatments. At 120 DAI, treatments T3, T5, T7 and control (T10) were on par with other treatments. The highest (203.84 cm^2g^{-1}) leaf area ratio was observed in *F. mosseae* with 50 g inoculum (T3) and least (35.69 cm^2g^{-1}) for *G. intradices* with 50 g inoculum (T6).

Table 51. Specific Leaf Area (cm^2g^{-1}) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Specific Leaf Area (cm^2g^{-1})					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	201.12	70.40	124.47	171.51^{ab}	92.83
T2	218.47	68.34	121.35	124.74^{abc}	100.53
T3	173.88	92.88	118.19	203.84^{a}	105.96
T4	161.85	78.54	108.45	103.15^{bc}	98.06
T5	198.87	90.43	115.66	113.75^{abc}	97.01
T6	199.95	80.73	110.53	35.69^{c}	112.68
T7	163.88	64.57	103.29	113.30^{abc}	116.60
T8	196.02	89.81	102.62	81.63^{bc}	117.92
T9	191.23	82.48	97.15	106.18^{bc}	114.12
T10	258.29	86.03	123.20	123.48^{abc}	99.74
SEm±	18.81^{ns}	3.02^{ns}	2.85^{ns}	10.94*	2.63^{ns}

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.3.4. Specific Leaf Weight

Analysis of variance revealed significant differences in specific leaf weight due to different treatments over time. In general, specific leaf weight at monthly intervals showed a decreasing trend with few exceptions (Table 52). At 30 DAI, 60 DAI, 90 DAI and 150 DAI, there was no significant variation in specific leaf weight due to various treatments. At 120 DAI, all except T6 were on par with other treatments. The highest (0.0677 g cm^{-2}) specific leaf weight was observed in *G. intradices* with 50 g inoculum (T6) and least (0.0049 g cm^{-2}) for *F. mosseae* with 50 g inoculum (T3).

Table 52. Specific Leaf Weight (g cm^{-2}) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Specific Leaf Weight (g cm^{-2})					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	0.0056	0.0156	0.0081	0.0064^{b}	0.0109
T2	0.0062	0.0154	0.0083	0.0094^{b}	0.0100
T3	0.0059	0.0110	0.0085	0.0049^{b}	0.0096
T4	0.0064	0.0131	0.0093	0.0103^{b}	0.0102
T5	0.0096	0.0111	0.0091	0.0099^{b}	0.0103
T6	0.0052	0.0125	0.0090	0.0677^{a}	0.0089
T7	0.0065	0.0161	0.0098	0.0096^{b}	0.0087
T8	0.0064	0.0111	0.0099	0.0148^{b}	0.0088
T9	0.0073	0.0127	0.0105	0.0100^{b}	0.0089
T10	0.0060	0.0118	0.0083	0.0112^{b}	0.0101
SEm±	0.0006^{ns}	0.0006^{ns}	0.0002^{ns}	0.0043*	0.0002^{ns}

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.3.5. Absolute Growth Rate

Analysis of variance revealed significant differences in absolute growth rate due to different treatments over time. Data pertaining to absolute growth rate at monthly intervals showed an increasing trend with few exceptions (Table 53). At 60 DAI, there was no significant variation in absolute growth rate due to various treatments. At 90 DAI, there was no significant variation in absolute growth rate due to various treatments. At 120 DAI, treatments T1, T2, T7, T8 and T10 were on par. The highest (0.32 cm day^{-1}) absolute growth rate was observed in *G. intradices* with 10 g inoculum (T4) and least (-0.13 cm day^{-1}) for *F. mosseae* with 50 g inoculum (T3). At the end of the study, treatments T5, T6 and T7 were on par. With regard to absolute growth rate, the highest value was (0.57 cm day^{-1}) recorded for *F. mosseae* with 50 g inoculum (T3)

and least absolute growth rate (-0.10 cm day^{-1})occurred in seedlings without AMF inoculation kept as control (T10).

Table 53. Absolute growth rate (cm day^{-1}) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Absolute growth rate (cm day^{-1})					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	-	-0.05	0.25	0.01^{ab}	0.46^{ab}
T2	-	-0.01	0.28	0.12^{ab}	0.44^{ab}
T3	-	0.08	0.29	-0.13^{b}	0.57^{a}
T4	-	0.04	0.32	0.32^{a}	0.25^{bc}
T5	-	0.17	0.20	-0.09^{b}	0.10^{cd}
T6	-	0.30	0.04	-0.12^{b}	0.10^{cd}
T7	-	0.09	0.04	0.08^{ab}	0.05^{cd}
T8	-	-0.03	0.03	0.11^{ab}	0.25^{bc}
T9	-	0.09	0.17	-0.09^{b}	0.45^{ab}
T10	-	0.06	0.17	0.08^{ab}	-0.10^{d}
SEm±	-	0.04^{ns}	0.04^{ns}	0.04*	0.05*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.3.6. Relative Growth Rate

Analysis of variance revealed significant differences in relative growth rate due to different treatments over time. However, relative growth rate at monthly intervals showed an increasing trend with few exceptions (Table 54). At 60 DAI, 90 DAI and 120 DAI, there was no significant variation in relative growth rate due to various treatments. At 150 DAI, treatments T5, T6 and T8 were on par. Data pertaining to relative growth rate at the end of the study, the highest value was (0.02 g $g^{-1}day^{-1}$) recorded for *G. proliferum* with 50 g inoculum (T9). The least relative growth rate (0.00 g $g^{-1}day^{-1}$) occurred in seedlings subjected to T4 and T7.

4.2.3.7. Net Assimilation Rate

Analysis of variance revealed there was no significant variation in net assimilation rate due to different treatments over time (Table 55).

Table 54. Relative Growth rate (g $g^{-1}day^{-1}$) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Relative Growth rate (g $g^{-1}day^{-1}$)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	-	0.00	0.01	0.00	0.01^{cd}
T2	-	0.01	0.01	0.00	0.01^{cd}
T3	-	0.01	0.01	0.00	0.02^{ab}
T4	-	0.00	0.01	0.01	0.00^{cd}
T5	-	0.01	0.01	0.00	0.01^{bc}
T6	-	0.01	0.01	0.00	0.01^{bc}
T7	-	0.01	0.00	0.01	0.00^{d}
T8	-	0.00	0.01	0.01	0.01^{bc}
T9	-	0.00	0.01	0.00	0.02^{a}
T10	-	0.01	0.01	0.00	0.01^{cd}
SEm±	-	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.00*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

Table 55. Net Assimilation rate (g $g^{-1}day^{-1}$) of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Net Assimilation rate (g $g^{-1}day^{-1}$)					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	-	0.00	0.00	0.00	0.00
T2	-	0.00	0.00	0.00	0.00
T3	-	0.00	0.00	0.00	0.00
T4	-	0.00	0.00	0.00	0.00
T5	-	0.00	0.00	0.00	0.00
T6	-	0.00	0.00	0.00	0.00
T7	-	0.00	0.00	0.00	0.00
T8	-	0.00	0.00	0.00	0.00
T9	-	0.00	0.00	0.00	0.00
T10	-	0.00	0.00	0.00	0.00
SEm±	-	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.00^{ns}

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.3.8. Physiological parameters

Analysis of variance revealed significant differences in chlorophyll content, photosynthetic rate, transpiration rate, leaf temperature, stomatal conductance, relative water content and plant water potential of the seedlings due different treatments (Table 56). With regards to chlorophyll content, the highest value was (54.00) recorded for seedling treated with *G. intradices* with 50 g inoculum (T6) and the least (34.63) chlorophyll content was occurred in seedlings without AMF inoculation kept as control (T10). Meanwhile, highest photosynthetic rate (7.45 µmol m^{-2} s^{-1}) was recorded for seedlings inoculated with *F. mosseae* with 10 g inoculum (T1) and the lowest value

(1.48 µmol m^{-2} s^{-1}) was observed in seedlings without AMF inoculation kept as control (T10). Transpiration rate was highest (1.61 µmol m^{-2} s^{-1}) in seedlings without AMF inoculation kept as control (T10) and it was the lowest in *G. proliferum* with 25 g inoculum (0.84 µmol m^{-2} s^{-1}). However, the leaf temperature was the highest (31.63 ^{o}C) for the seedlings kept as control (T10) and lowest (29.97 ^{o}C) value was recorded for the seedling subjected to *F. mosseae* with 10 g inoculum (T1). Data pertaining to the stomatal conductance, the highest value was (0.10 s cm^{-1}) observed for seedlings treated with *F. mosseae* with 25 g inoculum (T2) and the least (0.01 s cm^{-1}) stomatal conductance was occurred in seedlings subjected to *F. mosseae* with 10 g inoculum (T1). Exploration of date indicated that, the highest value of relative water content was (74.76 %) observed for seedlings treated with *F. mosseae* with 50 g inoculum (T3) and the least (63.80 %) relative water content was occurred in seedlings kept as control (T10). Meanwhile, the highest value of plant water potential (0.58 MPa) was recorded for seedlings inoculated with *F. mosseae* with 50 g inoculum (T3) and *G. proliferum* with 50 g inoculum. The lowest (0.40 MPa) plant water potential was observed in seedlings subjected to *F. mosseae* with 10 g inoculum (T1).

Table 56. Physiological parameters of *Swietenia macrophylla* as influenced by different treatments at 150 DAI

Treatments	Chlorophyll content	Photosynthesis rate (µmol m^{-2} s^{-1})	Transpiration rate (µmol m^{-2} s^{-1})	Leaf temperature (^{o}C)	Stomatal conductance (s cm^{-1})	Relative water content (%)	Plant water potential (MPa)
T1	39.40^{de}	7.45^{a}	0.34^{b}	29.97^{f}	0.01^{b}	68.31^{ab}	0.40^{b}
T2	54.00^{a}	4.75^{ab}	1.43^{a}	30.40^{e}	0.10^{a}	73.88^{ab}	0.48^{ab}
T3	45.60^{bcd}	5.66^{ab}	1.47^{a}	30.90^{d}	0.09^{a}	74.76^{a}	0.5^{a}
T4	46.07^{abc}	5.43^{ab}	1.24^{a}	30.87^{d}	0.08^{ab}	67.96^{ab}	0.47^{ab}
T5	51.57^{ab}	5.55^{ab}	1.50^{a}	30.87^{d}	0.09^{a}	71.31^{ab}	0.48^{ab}
T6	53.90^{a}	6.65^{ab}	1.46^{a}	31.23^{c}	0.09^{a}	73.96^{ab}	0.55^{a}
T7	42.30^{cd}	6.06^{ab}	1.53^{a}	31.40^{bc}	0.09^{a}	66.82^{ab}	0.50^{ab}
T8	47.53^{abc}	4.16^{b}	0.84^{ab}	31.43^{b}	0.04^{ab}	71.46^{ab}	0.48^{ab}
T9	48.27^{abc}	5.13^{ab}	1.36^{a}	31.53^{ab}	0.07^{ab}	73.34^{ab}	0.58^{a}
T10	34.63^{e}	1.48^{c}	1.61^{a}	31.63^{a}	0.09^{a}	63.80^{b}	0.42^{b}
SEm±	1.27*	0.36*	0.10*	0.10*	0.01*	1.06*	0.01*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.3. Per cent AMF colonization

Analysis of variance revealed significant differences in colonization percentage and total number of spores in the soil due different treatments (Table 57). With regards

to colonization percentage, the highest value was (42.00 %) recorded for seedling treated with *G. intradices* with 50 g inoculum (T6) and the least (0.00) colonization percentage was occurred in seedlings without AMF inoculation kept as control (T10). Meanwhile, highest spore count (122.33) was recorded for seedlings inoculated with *F. Mosseae* with 50 g inoculum (T3) and the lowest value (8.00) was observed in seedlings without AMF inoculation kept as control (T10).

Table 25. Per cent of AMF and number of AMF spores in *Swietenia macrophylla* as influenced by different treatments at 150 DAI

Treatments	Root colonization (%)	Number of spores/10 g soil
T1	22.00^{e}	50.67^{e}
T2	28.33^{de}	83.33^{c}
T3	55.67^{a}	122.33^{a}
T4	24.33^{e}	33.00^{f}
T5	36.00^{bc}	54.67^{de}
T6	42.00^{b}	99.33^{b}
T7	15.00^{f}	35.00^{f}
T8	25.00^{e}	44.33^{ef}
T9	34.33^{cd}	65.00^{d}
T10	0.00^{g}	8.00^{g}
SEm±	2.73*	6.08*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.4. Quality assessment

4.2.4.1. Biovolume index

Analysis of variance revealed significant differences in biovolume index due to different treatments over time. Consequently, biovolume index at monthly intervals showed an increasing trend (Table 58). At 30 DAI, all except T2 and control (T10) were on par. The highest (59.47) biovolume index was observed in *F. mosseae* with 25 g inoculum (T2) and least (26.13) for control (T10). At 60 DAI, there was no significant variation in biovolume index due to various treatments. At 90 DAI, treatments T3 and T6 were on par. The highest (159.93) biovolume index was observed in *F. mosseae* with 25 g inoculum (T2) and least (69.05) for *G. proliferum* with 25 g inoculum (T8). At 120 DAI, all except T1, T2 and T4 were on par with other treatments. The highest (244.64) biovolume index was observed in *G. intradices* with 10 g inoculum (T4) and least

(73.32) for control (T10). At the end of the study, T4, T7 and control (T10) were on par. A similar trend was followed in next month biovolume index. With regard to biovolume index at the end of the study, the highest value was (360.46) recorded for *G. intradices* with 10 g inoculum (T4). Data pertaining to next higher and comparable biovolume index was observed in seedlings subjected to *F. mosseae* with 25 g inoculum (T2) (319.98) and *F. mosseae* with 50 g inoculum (T3) (320.53). The least (121.16) biovolume index occurred in seedlings without AMF inoculation kept as control (T10). Greater than threefold increase biovolume index was observed in seedlings subjected to *G. intradices* with 10 g inoculum compared to control at the end of the study.

Table 58. Biovolume index of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Biovolume index					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	48.80^{ab}	45.96	97.27^{bcd}	110.71^{bc}	253.96^{bc}
T2	59.47^{a}	62.80	159.93^{a}	146.83^{b}	319.98^{ab}
T3	38.43^{ab}	59.49	116.02^{abcd}	104.06^{c}	320.53^{ab}
T4	52.22^{ab}	65.50	129.43^{abc}	244.64^{a}	360.46^{a}
T5	49.15^{ab}	82.58	145.69^{ab}	95.41^{c}	174.44^{cde}
T6	38.22^{ab}	81.14	110.47^{abcd}	95.17^{c}	149.48^{de}
T7	49.30^{ab}	75.43	84.50^{cd}	105.97^{c}	138.10^{e}
T8	46.31^{ab}	51.68	69.05^{d}	83.22^{c}	172.54^{cde}
T9	48.63^{ab}	51.17	86.81^{cd}	79.49^{c}	241.77^{bcd}
T10	26.13^{b}	41.79	69.31^{d}	73.32^{c}	121.16^{e}
SEm±	2.63*	4.47^{ns}	7.04*	9.51*	17.18*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.3.2. Seedling Quality index

Analysis of variance revealed significant differences in seedling quality index due to different treatments over time. While, seedling quality index at monthly intervals showed an increasing trend (Table 59). At 30 DAI, treatments T1, T2, T6, T8 and T9 were on par. The highest (0.21) seedling quality index was observed in *G. intradices* with 25 g inoculum (T5) and *G. proliferum* with 10 g inoculum (T7). The least (0.09) seedling quality index observed for control (T10). At 60 DAI, treatments T2, T3 and T4 were on par. The highest (0.39) seedling quality index was observed in *G. intradices* with 25 g inoculum (T5) and least (0.20) for *G. proliferum* with 50 g inoculum (T9) and for control (T10). At 90 DAI, all except T2, T5 and control (T10) were on par with other treatments. The highest (0.60) seedling quality index was observed in *F. mosseae*

with 25 g inoculum (T2) and data pertaining to next higher and comparable (0.56) seedling quality index recorded for *G. intradices* with 25 g inoculum (T5). The least (0.29) seedling quality index recorded for control (T10). At 120 DAI, treatments T1, T2 and T7 were on par. The highest (0.66) seedling quality index was observed in *G. intradices* with 10 g inoculum (T4) and least (0.27) for control (T10). At the end of the study, treatments T1, T2, T8 and control (T10) were on par. With regard to quality index, the highest value was (0.88) recorded for *G. proliferum* with 50 g inoculum (T9) followed by *F. mosseae* with 50 g inoculum (T3) (0.84). The least quality index occurred in seedlings without AMF inoculation kept as control (T10) (0.09) at the end of the study.

Table 59. Seedling Quality Index of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Seedling Quality Index					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	0.17^{ab}	0.23^{bc}	0.46^{ab}	0.57^{ab}	0.75^{abcd}
T2	0.16^{ab}	0.33^{abc}	0.60^{a}	0.54^{ab}	0.74^{abcd}
T3	0.09^{b}	0.24^{abc}	0.37^{ab}	0.45^{abc}	0.84^{ab}
T4	0.20^{a}	0.32^{abc}	0.49^{ab}	0.66^{a}	0.81^{abc}
T5	0.21^{a}	0.39^{a}	0.56^{a}	0.40^{bc}	0.64^{bcd}
T6	0.10^{ab}	0.19^{c}	0.38^{ab}	0.39^{bc}	0.60^{d}
T7	0.21^{a}	0.37^{ab}	0.44^{ab}	0.56^{ab}	0.62^{cd}
T8	0.16^{ab}	0.23^{bc}	0.38^{ab}	0.43^{abc}	0.70^{abcd}
T9	0.20^{ab}	0.20^{c}	0.41^{ab}	0.43^{abc}	0.88^{a}
T10	0.09^{b}	0.20^{c}	0.29^{b}	0.27^{c}	0.70^{abcd}
SEm±	0.01*	0.02*	0.02*	0.03*	0.02*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.3.3. Mycorrhizal Efficiency Index

Analysis of variance revealed significant differences in mycorrhizal efficiency index due to different treatments over time. Data pertaining to mycorrhizal efficiency index at monthly intervals showed an increasing trend (Table 60). At 30 DAI and 60 DAI, there was no significant variation in mycorrhizal efficiency index due to various treatments. At 90 DAI, treatments T1, T3, T6, T7 and T9 were on par. The highest (49.18) mycorrhizal efficiency index was observed in *G. intradices* with 25 g inoculum (T5) and least (0.00) mycorrhizal efficiency index recorded for control (T10). At 120 DAI, treatments T5, T8 and T9 were on par. The highest (67.37) mycorrhizal efficiency index was observed in *G. intradices* with 10 g inoculum (T4) and least (0.00) for control

(T10). At the end of the study, treatments T1, T2, T3, T4 and T9 were on par. With regard to mycorrhizal efficiency index, the highest value was (66.43) recorded for *F. mosseae* with 50 g inoculum (T3). Similarly, the next lower and comparable mycorrhizal efficiency index recorded in seedlings subjected to *G. intradices* with 10 g inoculum (T4) and *G. proliferum* with 50 g inoculum (T9). The least mycorrhizal efficiency index occurred in seedlings without AMF inoculation kept as control (T10) (0.00) at the end of the study.

Table 60. Mycorrhizal Efficiency Index of *Swietenia macrophylla* as influenced by different treatments at monthly intervals

Mycorrhizal Efficiency Index					
Treatments	**30 DAI**	**60 DAI**	**90 DAI**	**120 DAI**	**150 DAI**
T1	37.07	-5.20	39.62^{ab}	48.60^{abc}	51.84^{a}
T2	20.45	41.09	48.16^{a}	55.66^{ab}	56.58^{a}
T3	-7.94	10.81	24.78^{ab}	31.63^{bcd}	66.43^{a}
T4	48.08	35.53	48.54^{a}	67.37^{a}	65.84^{a}
T5	23.11	47.07	49.18^{a}	30.44^{cd}	11.59^{bc}
T6	-2.61	-0.40	27.43^{ab}	20.36^{de}	11.53^{bc}
T7	46.83	38.25	21.32^{ab}	46.37^{abc}	15.32^{bc}
T8	39.97	2.39	-6.35^{b}	26.12^{cd}	38.15^{ab}
T9	21.35	-28.49	24.43^{ab}	25.19^{cd}	65.39^{a}
T10	0.00	0.00	0.00^{b}	0.00^{e}	0.00^{c}
SEm±	6.51^{ns}	8.02^{ns}	5.11*	4.00*	5.53*

**Significant at 0.05 levels*

Values with same superscript in column at different month are homogenous

4.2.5. Cluster analysis

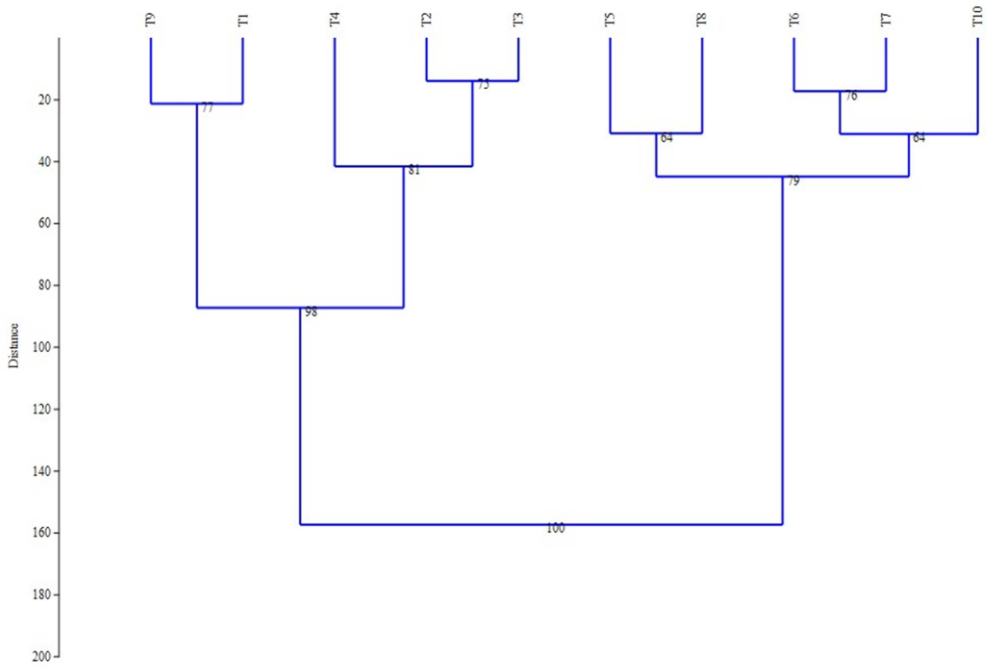
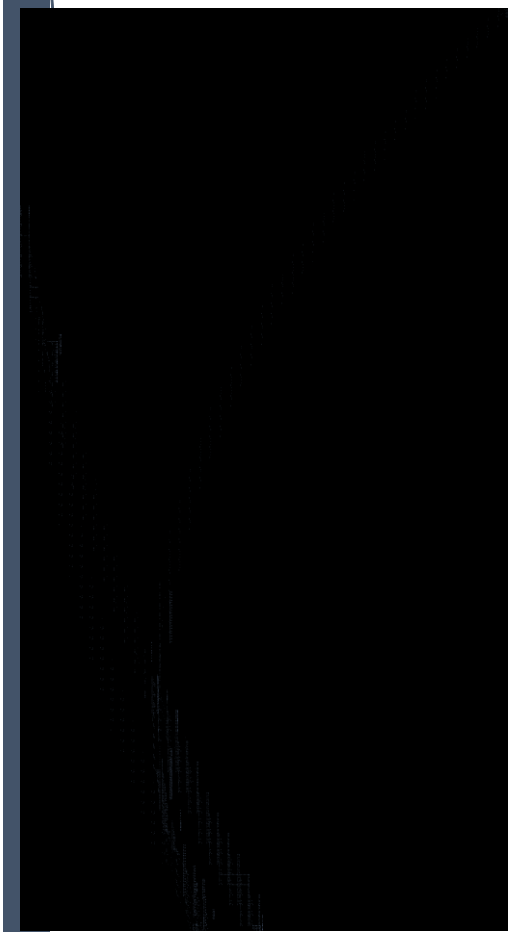


Fig.3. The dendrogram of the cluster analysis of *Swietenia macrophylla* subjected to different treatments

The dendrogram of the cluster analysis of *Swietenia macrophylla* subjected to different AMF species with various levels of mycorrhiza are presented Figure 2. Cluster analysis identified two clusters. First cluster contained the seedlings subjected to *G. intradices* with 25 g inoculum (T5), *G. intradices* with 50 g inoculum (T6), *G. proliferum* with 10 g inoculum (T7), *G. proliferum* with 25 g inoculum (T8), *F. mosseae* with 10 g inoculum (T1) and seedlings kept as control (T10). The second cluster contained the seedlings subjected to *F. mosseae* with 50 g inoculum (T3), *G. intradices* with 10 g inoculum (T4), *F. mosseae* with 25 g inoculum (T2) and *G. proliferum* with 50 g inoculum (T9).

DISCUSSION



5. DISCUSSION

The results obtained on the role of arbuscular mycorrhizal fungi (AMF) in quality seedling stock production of Teak (*Tectona grandis*) and mahogany (*Swietenia macrophylla*) are discussed in this chapter. The Arbuscular Mycorrhizal Fungi (AMF) is ubiquitous in nature and is seen in symbiotic association with the roots of higher plants. The predominant genus occurring in Kerala is *Glomus* which is adaptable to a wide range of soil and environmental factors (Harikumar and Potty, 1999; Gopal *et al*., 2005). This predominant nature of *Glomus* was the reason behind the selection of native AMF species (*Funelliformis mosseae, Glomus intradices, Glomus proliferum*) for screening at various levels (10, 25 and 50 g inoculum per seedling).

Arbuscular mycorrhizal fungi at different level significantly influenced the various growth characteristics of the seedlings. Significant increase was found in shoot height, collar girth, number of leaves, leaf area, tap root length, number of lateral root, fresh weight of roots, shoots and leaves, dry weight of roots, shoots and leaves, total fresh weight, total dry weight, vigour index and root: shoot ratio in *Tectona grandis* and *Swietenia macrophylla* due to different treatments as compared to control.

From the studies in *Swietenia macrophylla* seedlings, it was apparent that mycorrhizal inoculation significantly influences the growth of the seedlings. Significantly higher height growth was observed in all levels of *Funelliformis mosseae* inoculation (10, 25 and 50 g inoculum) and *Glomus intradices* at lower level of inoculation (10 g inoculum). Seedling height increase due to AMF inoculation has been reported in several studies (Rajan *et al*., 2000; Wu *et al*., 2011; Binu *et al*., 2015). In present study seedling height enhancement was up to 100 per cent (Table 1). This could be attributed efficiency and suitability of AMF for these species. Further, it was also observed that the collar diameter and total biomass accumulation were higher in all levels of *F. mosseae*, lower level of *G. intradices* and medium in different level of *G. proliferum*. The data on photosynthetic area and chlorophyll content indicated a higher value pertaining to these inoculation levels. The higher photosynthetic area and chlorophyll content might have leads to the accumulation of photosynthates (Table 26 and 56). Similarly, the result obtained from *Tectona grandis* indicate higher height

growth and biomass accumulation in seedlings with *G. proliferum* at higher (50 g inoculum) and medium (25 g inoculum) level of inoculation (Table 31-55). From 60 Days after inoculation (DAI) onwards seedlings inoculated with *G. proliferum* with 50 g inoculum was superior to the other treatments. It indicates the host suitability of *G. proliferum* with teak. It is clear that the higher (50 g inoculum) level of inoculation is needed to provide sufficient nutrient subsequent and growth of the seedlings. It was evident from the spore count in the poly bags and colonization percentage (Table 26 and 57).

The enhanced growth due to the presence of AMF in the root system of plants is already known to improve plant health and growth (Auge, 2001). A plant with a well established symbiont is better off because of increased resistance to various stress factors. The intimate interrelationship between the mycorrhizal symbiont and the plant ensures that it will be highly responsive to management practices (Sikora, 1992). These responses include production of metabolites like amino acids, vitamins, phytohormones, and/or solubilisation and mineralization processes (Nadeem *et al*., 2014). These fungi penetrate into root cortical cells and form a particular haustoria-like structure called arbuscule that serves as a mediator for the exchange of metabolites between fungus and host cytoplasm (Oueslati, 2003). The AMF hyphae also proliferate into the soil which helps plants to acquire mineral nutrients and water from the soil and also contribute to improving soil structure (Rillig and Mummey, 2006).

The process of root inoculation by the fungi consists of complex stages including spore germination, hypha differentiation, aprosurium formation, root penetration, intercellular growth, arbuscule formation and nutrient transfer (Harrier, 2001). Arbuscules are branched hypha, found inside root cells from where nutrient exchange takes place between fungi and the host plant (Van Duin *et al*., 1989; Entry *et al*., 2002; Troeh and Loynachan, 2003). It can increase plant tolerance to biotic and abiotic stresses (Subramanian and Charest, 1997). One of the unique characteristics of AMF, when in symbiotic relationship with plant roots, is the significant increase in root surface area due to the production of extensive hypha helping plants grow under relatively harsh conditions, such as drought stress (Al Karaki *et al*., 2004) and nutrient deficiency conditions (Marschener and Dell, 1994). The fungi do this by growing

beyond the nutrient depletion zones that typically form around roots, and by greatly increasing the absorptive surface of the root system (Smith and Read, 2008). Arbuscular mycorrhizal fungi are able to take up nutrients in inorganic forms (Marschner and Dell, 1994). There is some evidence to suggest that AMF may access nutrients from organic sources (Hodge *et al*., 2001; Hodge and Fitter, 2010), this most likely occurs following the mineralization of nutrients in organic matter (Smith and Smith, 2011). Arbuscular mycorrhizal fungi have the potential to promote plant nutrition and growth, and reduce nutrient leaching. Enhanced plant phosphorus (P) uptake is generally considered the main benefit of AM to plants (Abbott and Robson, 1984). Enhanced the uptake of nitrogen (Leigh *et al*., 2009), zinc (Ryan and Angus, 2003; Seres *et al*., 2006), copper (Toler *et al*., 2005) and iron (Kim *et al*., 2009) among others (Ryan *et al*., 2004) to have been reported.

Our results were as conformity with the studies of Rajan *et al.* (2000), who screened selected AMF for their symbiotic efficiency with *Tectona grandis*. Teak plants grown in the presence of AMF showed a general increase in plant growth parameters like plant height, stem girth, leaf area and total dry weight as against those grown in soils uninoculated with AM fungus. They found that *G. macrocarpum* significantly enhancing the plant height as compared to all other treatments except for *G. margarita*. However, seedlings raised in the presence of *G. leptotichum* had a significantly higher stem girth than other treatments except *G. fasciculatum*. The total photosynthetic area expressed as the leaf area was significantly more in plants grown in the presence of *G. leptotichum*. They concluded that increased leaf area and enhanced nutrient content in seedlings colonized by *G. leptotichum* have probably resulted in significantly higher biomass compared to other treatments.

Glomus mosseae was found as the most promising and the best AMF symbiont for inoculating *Azadirachta indica* seedlings in the nursery (Sumana and Bagyaraj, 2003). Plant height, number of leaves and stem girth were significantly greater in plants inoculated with G. *mosseae* when compared with uninoculated plants. Plant biomass was enhanced by about 70 per cent due to G. *mosseae* inoculation compared with uninoculated plants. Shoot and root biomass were also significantly higher in plants inoculated with *G. mosseae* and the lowest biomass was observed in uninoculated

seedlings (Sumana and Bagyaraj, 2003). Such an increase in biomass was reported by Vasanthakrishna *et al.* (1995) in *Casuarina equisetifolia* and Rajan *et al.* (2000) in *Tectona grandis* when inoculated with AMF species. Similar observations were reported in *Dalbergia sissoo* which showed higher biomass content because of inoculation with G. *fasciculatum* (Sumana and Bagyaraj 1996). Mycorrhizal symbiosis (*G. mosseae*) significantly improved plant growth performance, such as plant height, stem diameter, shoot, root or total dry weight compared with the non-AMF *Prunus persica* seedlings (Wu *et al*., 2011). Compared with the non-AMF treatment, plant height, stem diameter, shoot, root or total dry weight was significantly increased by 30.3 per cent, 17.2 per cent, 34.4 per cent, 64.5 per cent or 45.4 per cent respectively with the inoculation of *G. mosseae*.

The control seedlings had greater height, leaf area and dry matter in *Azadirachta excelsa* seedlings treated with *G. mosseae* and *S. calospora* (Huat *et al*., 2002). *Anacardium occidentale* seedlings were inoculated with three species of AMF viz. *G. aggregatum*, *G. fasciculatum* and *G. mosseae.* Among these *G. fasciculatum* had significantly greater stem girth, number of leave and intermodal length than the uninoculated plants (Ananthakrishnan *et al*., 2004). Inoculation with three AMF (*G. occultum, G. mosseae* and *G. aggregatum*), resulted in significant increase in shoot height, diameter and leaf area of *Acacia mangium* compared to the control plants (Ghosh and Verma, 2006). *G. occultum* inoculated seedlings had higher biomass than seedlings inoculated with other AMF species.

Enhanced growth of *Acacia holosericea* was recorded when the plants were inoculated with *G. intraradices* (Duponnois and Plenchette, 2003) and *G. aggregatum* (Duponnois *et al.* 2001). Mycorrhizal inoculation in *D. sissoo* stimulated plant growth under glasshouse conditions, which could be of importance for its survival and growth in natural conditions (Bisht *et al*., 2009). There were variations in height, number of leaves, leaf area, shoot weight and relative water content of *Santalum album* seedlings due to AMF inoculation (Binu *et al*., 2015) and *G. mosseae* performed better under partial shade.

Mycorrhizal inoculation are not always equally effective in all species and they certainly vary in their physiological interaction with different plant and hence in their

effects on plant growth. The seedling growth decreased in of *Azadirachta excelsa* when AMF species was introduced in the nonsterile soil suggesting that introduced species are less effective than the native species. Another explanation is the existence of antagonistic relationship between the native AMF and tropical trees (Cuenca *et al*., 1990; Huat *et al*., 2002).

Neem seedlings were inoculated with AMF with sub-optimal levels (Muthukumar *et al*., 2001). Although, the inoculated seedlings had greater plant height, stem girth, leaf number and area compared to noninoculated controls both at 60 and 120 Days After Transplanting. Results of other studies generally agree with previous reports on the positive growth response of tree seedlings to AM fungi in unsterile soil (Young 1990; Michelsen 1993), it contradicts reports where indigenous AM fungi were found to be ineffective or less effective (Bagyaraj *et al*. 1989; Reena and Bagyaraj 1990) compared to exotics. However, in some of the very few previously reported trials with tropical trees in nonsterile soils, mycorrhizal inoculation failed to improve tree seedling growth (Cuenca *et al*., 1990). Similarly, AMF inoculation did not affect collar girth, root weight and root length of sandal seedlings (Binu *et al*., 2015).

In the present experiment, the inoculation with AMF significantly influenced the physiological parameters (Table 26 and 56) in both *T. grandis* and *S. macrophylla*. *S. macrophylla* with higher chlorophyll content was recorded for all medium levels (25 g inoculum) and higher levels (50 g inoculum) of AMF. It resulted in higher photosynthetic rate and leaf area (Table 4 and 34). Higher leaf temperature was recorded for the control and suggesting better transpiration rate and lower water potential in AMF inoculated plants. Similarly, in *T. grandis,* Chlorophyll content was higher for higher levels of inoculation irrespective of AMF strains. This indicates that AMF inoculations at lower levels are not sufficient for the altering physiological activities. Physiological processes involved in osmoregulation like enhanced carbon dioxide exchange rate, water use efficiency, and stomatal conductance can be influenced by the activities of AMF (Birhane *et al*., 2012). It has been shown that mycorrhizal plants absorb water more efficiently under water deficit environment (Khalvati *et al*., 2005) which might be due to modification in root architecture which results in better root growth due to numerous branched roots (Berta *et al*., 2005).

The high percentage of root colonization in AMF treated plants is directly correlated with a better nutrient uptake, increased total chlorophyll content, an increase in the rate of photosynthesis and transpiration (Eissenstat *et al*., 1993; Peng *et al*., 1993; Mathur and Vyas, 1995; Rajasekaran and Nagarajan, 2005), and thereby improved root and shoot growth (Thaker and Fasrai, 2002; Farshian *et al*., 2007). These results are also in conformity with several others (Azam and Jalil, 2007; Dutt *et al*., 2013) were recorded an increase of total chlorophyll when inoculated with AMF species. The AMF inoculated plants have a comparatively low transpiration rate and higher water use efficiency (WUE) as compared with non mycorrhizal plants. This reduced transpiration rate is due to increased stomatal resistance provided by the AMF colonization by decreasing stomatal conductance (Mathur and Vyas, 1995). Abbaspour *et al*., (2012) suggest controversies to above that mycorrhiza could increase the rate of leaf transpiration, reduce leaf temperature and restrain the decomposition of chlorophyll, which was not true as per the present study.

Inoculation with three AMF (*G. occultum, G. mosseae* and *G. aggregatum*), resulted in significant increase in chlorophyll content of *Acacia mangium* compared to the control plants (Ghosh and Verma, 2006). Mycorrhizal inoculation (*G. mosseae* and *S. calospora*) significantly reduced photosynthetic rate (31 per cent) in *Azadirachta excelsa* seedlings (Huat *et al*., 2002). The presence of AMF on root system of plants is correlated with higher rates of net photosynthesis (Reid *et al*., 1983; Nylund and Unestam, 1987). The difference in photosynthetic rate could probably be due to excessive starch accumulation in leaves of seedlings inoculated with AMF. Maximum photosynthetic rates in the *Dalbergia sissoo* were observed in AMF inoculated plants, an effect corroborated by increased root biomass (Bisht *et al*., 2000). Since mycorrhizal infection often results in increased allocation of C to the root system, it implies increased root biomass, increased root respiration and mycelial biomass which could explore a larger soil volume for nutrient, consequently resulting in higher uptake rates (Jakobsen 1995). The transpiration rates for plants inoculated with AMF were higher, which could also explain higher nutrient content in the shoots of plants grown in these soils. Changes in transpiration could cause a change in the rate of photosynthesis changing the supply of carbohydrate to the fungus. Alternatively, higher nutrient uptake

due to higher transpiration rates could be due to mass flow of nutrients towards the root (Sharma *et al.* 1991; Bisht *et al*., 2000).

Relative water content was higher in seedlings inoculated with AMF compared with uninoculated seedlings. This indicated that the seedlings had better plant water status. Relative water content was higher for seedlings inoculated with AMF, particularly those inoculated with *G. mosseae* grown under 50 and 25 per cent shade (Binu *et al*., 2015). Thus, in the long run, metabolic process and growth of sandal seedlings will be superior in these seedlings (Sinclair and Ludlow 1985).

The AMF species and levels of inoculation significantly influenced the colonization per cent (Table 27 and 57). These results indicated that a higher AMF inoculum level is required for increasing the per cent root colonization which in turn increased the quality of seedlings. With regards to colonization percentage, the higher values were recorded for seedling treated with all higher levels of AMF in *S. macrophylla*. In *T. grandis* higher root colonization per cent was observed in *G. proliferum* with higher (50 g inoculum) and higher spore count for *G. proliferum* with higher level (50 g inoculum). Establishment of symbiosis involves a range of factors which can impact on the AMF association, both directly, by damaging or killing AMF and indirectly, by creating conditions either favourable or unfavourable to AMF. In general, it is an interaction of host, Fungi and soil factors.

This work is in confirmation with the results of Daft and Nicolson (1968) and Ferguson (1981) who examined the influence of inoculation dosage on rate of colonization and concluded that increased inoculums dosage resulted in increased colonization and thereby increased the biomass production.

Rajan *et al*. (2000) observed that per cent root colonization observed *G. margarita* inhabited a significantly higher percentage of roots compared to other AMF in screening of selected AMF for their symbiotic efficiency with *T. grandis*. However, spore numbers were highest in soil samples inoculated with *G. leptotichum*, indicating the better proliferating ability of this fungus with teak as the host. This capacity of *G. leptotichum* to sporulate and hence multiply faster is of great significance as it will not only increase the colonization of the roots further, but also improve the mycorrhizal

potential of the soil to which it would be transplanted. The ability of this species to improve considerably the growth and nutrient content of teak plants and to sporulate in higher numbers despite a significantly lower colonization level compared to *G. margarita, G. macrocarpum* and *G. mosseae* further emphasizes that *G. leptotichum* utilizes the carbon sources of teak seedlings efficiently, an observation which supports the work of Abbott and Robson (1985). Mycorrhizal fungi are also implicated in improving the soil structure by increasing the soil aggregation by their hyphae (Miller and Jastrow, 1992). Soil aggregation is a measure of the amount of extramatrical hyphae, which is in turn related to the efficiency of the fungus (Reena and Bagyaraj, 1990).

The mycorrhizal infection of *Azadirachta excelsa* seedlings was high (81.25 per cent) with *G. mosseae*. This was probably because *A. excels* possesses coarse root and relatively fewer root hairs. This is consistent with findings of previous researchers (Jasper *et al*., 1989; Brundertt, 1991). Plant species with coarse rooting system and few root hairs appear to be more dependent on mycorrhiza for mineral nutrient uptake (Huat *et al*., 2002). Sumana and Bagyaraj (2003) reported that the highest root colonisation and spore numbers were observed in plants inoculated with G. *mosseae* and the lowest colonisation and spore numbers were experienced by uninoculated neem seedlings. The biovolume index and quality index were significantly more in plants inoculated with G. *mosseae.* Uninoculated plants had recorded the lowest biovolume and quality indices (Sumana and Bagyaraj, 2003). In a study *Prunus persica* seedlings was inoculated with *Glomus mosseae*, *G. versiforme*, and *Paraglomus occultum*, respectively (Wu *et al*., 2011). After 100 days of mycorrhizal inoculations, mycorrhizal colonization of one-year-old seedlings ranged from 23.4 per cent to 54.9 per cent. The Acacia inoculum contained an average of 295 live spores 50 g^{-1} soil, while Prosopis inoculums contained 458 live spores 50 g^{-1}, *G. etunicatum* was dominant in the former and G. claroideum dominated the latter (Munro *et al*., 1999).

Anacardium occidentale seedlings were inoculated with three species of AMF viz. *G. aggregatum*, *G. fasciculatum* and *G. mosseae* (Ananthakrishnan *et al*., 2004). The mycorrhizal colonization percentage was varied with species and highest for *G. mosseae*. Extra matrical chlamydospore counts from root zone soil of the inoculated

plants also varied. Similar result was observed by Sivaprasad *et al*. (1992) in cashew. Species and strains of AMF were different in their ability in the nutrient uptake and influencing plant growth (McGraw and Schenck, 1980; Bagyaraj, 1992). Inoculation with AMF showed increase in percentage of colonised root of sandal seedling which increased with time (Binu *et al*., 2015). Maximum colonisation percentage was for seedlings inoculated with *G. mosseae* and grown under 50 per cent shades. The control plants recorded a lower spore count. The root exudates from the host plants might have stimulated the spore production of AMF which is in confirmation with the findings of Bacard and Piche (1989). They observed the presence of a growing root fungal contact and active fungal growth ceased upon root removal. The decreases in spore count naturally led to decrees in per cent root colonization.

Quality assessments of seedlings were done by the calculation of biovolume index, quality index and Mycorrhizal Efficiency Index (MUE). With regard to seedling quality index, the higher value was recorded for all level of *F. mosseae,* lower level of *G. intradices* (10 g inoculum) and higher level of *G. proliferum*. In *T. grandis* the higher quality parameters were recorded for the higher level of *G. proliferum* and followed by the medium level. This might be due to the higher inoculum density. As the AMF inoculums density was more the ability of the AMF spores to form symbiotic associations with the root system was increased resulting in higher per cent root colonization.

Mycorrhizal Efficiency Index is a direct measurement of efficiency of AMF innoculation. Cruz *et al*. (1999) categorized the Mycorrhizal Efficiency Index (MUE) in three groups: 40 per cent and above: high efficiency; 10-40 per cent: moderate efficiency; below 10 per cent: no efficiency. *A. mangium* showed 57 per cent efficiency on *G. occultum*, 47 per cent on *G. mosseae* and 46 per cent on *Glomus aggregatum* (Ghosh and Verma, 2006). The high MUE value suggested that inoculation would be useful in production of vigorous seedlings in the nursery which might establish better in the field and withstand drought, nutrient deficiency and pathogenic infections (Ghosh and Verma, 2006).

Teak seedlings raised in the presence of *G. leptotichum* showed a greater biovolume index and quality index compared to all other treatments and this increase

was to an extent of 68 per cent and 66.7 per cent, respectively, over those seedlings raised in soil uninoculated with AM fungus (Rajan *et al*., 2000). Such high values of biovolume index and quality index indicate a sturdier stem and a proportionate top dry weight compared to the seedling dry weight, qualities which are desirable among nursery seedlings (Hatchell, 1985). Inoculation with *G. intraradices, G. geosporum*, PSB and *A. brasilense* improved the seedling quality by 104 per cent compared to uninoculated controls and by 25-93 per cent over other treatments in *Azadirachta indica* (Muthukumar *et al*., 2001).

The determination of optimum inoculation level is very important for the selection of the best AMF. The optimum inoculation level varied with the host and soil factors. The inoculation level and species suitability are important in the short nursery period, so we can go for the pre-inoculation of tree seedlings in the nursery before transplanting to the field. Such seedlings have the potential to survive for a longer time and thereby give more biomass accumulation.

SUMMARY

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6. SUMMARY

Possibilities of using arbuscular mycorrhizal fungi for production of quality seedlings of two commercially important timber species viz., Teak (*Tectona grandis*) and Mahogany (*Swietenia macrophylla*) were explored through a nursery study conducted at the Tree nursery, College of Forestry, Vellanikara, Thrissur, Kerala during 2013-2015. The main objective of the study to assess the impact of inoculation potential of selected AMF on growth and quality of *Tectona grandis* and *Swietenia macrophylla* seedlings.

The *T. grandis* and *S. macrophylla* seedlings were raised in field condition. Three native AMF species (*Funelliformis mosseae, Glomus intradices, Glomus proliferum*) were applied with three doses (10, 25 and 50 g inoculum per seedling). The growth attributes and physiological parameters were recorded for six months after application of AMF. At the end of the sixth month, representative seedlings were destructively sampled for quantification of mycorrhizal colonization percentage and total spore count. The quality of seedlings and mycorrhizal use efficiency were calculated. The experiment was laid out in a factorial RBD with control.

The salient findings of the study are as follows.

1. Treatments of AMF at different doses significantly influenced the biometric observations such as shoot height (23.83% over control), collar girth (42.52 %), tap root length (66.40%) and total fresh weight (8.76%) of *Tectona grandis* increased due to inoculation.
2. In *Swietenia macrophylla* also biometric observations shoot height (46.12%), collar girth (72.98%), tap root length (67.02%) and total fresh weight (36.06%) were significantly influenced as compared to the control.
3. Seedlings treated with *G. intradices* with 10 g inoculum recorded maximum height, collar diameter, leaf area, number of lateral roots and biomass accumulation at different stages of growth in *Swietenia macrophylla.*
4. In *Tectona grandis* the *G. proliferum* with 50 g inoculum recorded maximum height, collar diameter, leaf area, number of lateral roots and biomass accumulation at different stages.

5. Treatments significantly influenced the vigour indexes of *Swietenia macrophylla* (2.82% increment over control) and *Tectona grandis* (43.45% increment over control) seedlings.
6. The growth observations like LAR, LWR, LAD, SLA, SLW, AGR, RGR and NAR showed a significant difference among the treatments in *Swietenia macrophylla* and *Tectona grandis* seedlings.
7. With a few exceptions, seedling growth observations and physiological parameters increased with the increase in inoculation doses.
8. Mycorrhizal inoculations significantly influenced chlorophyll content, photosynthetic rate, transpiration rate, plant water potential, stomatal conductance, relative water content and leaf temperature in *Swietenia macrophylla* seedlings.
9. In case of *Tectona grandis* seedlings chlorophyll content, leaf temperature and relative water content showed significant differences between treatments. But the photosynthetic rate, transpiration rate, stomatal conductance and plant water potential was not influenced by it.
10. Colonization percentage and total spore count significantly increased with increase in inoculation levels in *Swietenia macrophylla* and *Tectona grandis*.
11. With AMF inoculation the nursery period of seedlings can be reduced to five months from one year thereby cutting down the cost of manufacture of seedlings in the tree nursery.

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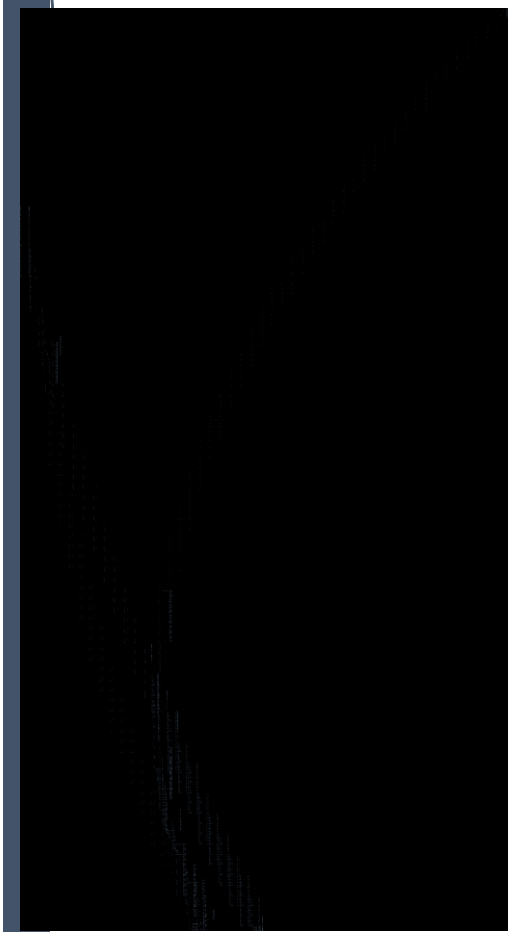

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Harnessing arbuscular mycorrhizal fungi (AMF) for quality seedling stock production of *Tectona grandis* Linn. and *Swietenia macrophylla* King.

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ABSTRACT

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ABSTRACT

A study was conducted to find efficacy of three native species of arbuscular mycorrhizal fungi (AMF) on *Tectona grandis* Linn. and *Swietenia macrophylla* King. at Tree nursery, College of Forestry, Vellanikara, Thrissur, Kerala during 2013-2015. The study assessed the impact of inoculation of selected AMF on growth and quality of seedlings. The native AMF species (*Funelliformis mosseae, Glomus intradices, Glomus proliferum*) at different levels (10, 20 and 50 g inoculum per seedling) were applied on the seedlings raised in polythene bags. The experiment was laid out in a factorial RBD with control.

Seedlings raised in the presence of AMF showed a significant difference in plant growth and quality over those grown in the absence of AMF. The extent of growth and quality enhancement differed among AMF species and levels of inoculation. In general, mycorrhizal symbiosis significantly improved plant growth performance, such as plant height, stem diameter, shoot, root or total dry weight. Mycorrhizal colonization of seedlings ranged from 17.3 per cent to 56.3 per cent in *S. macrophylla* and 15.0 per cent to 36.0 per cent in *T. grandis*.

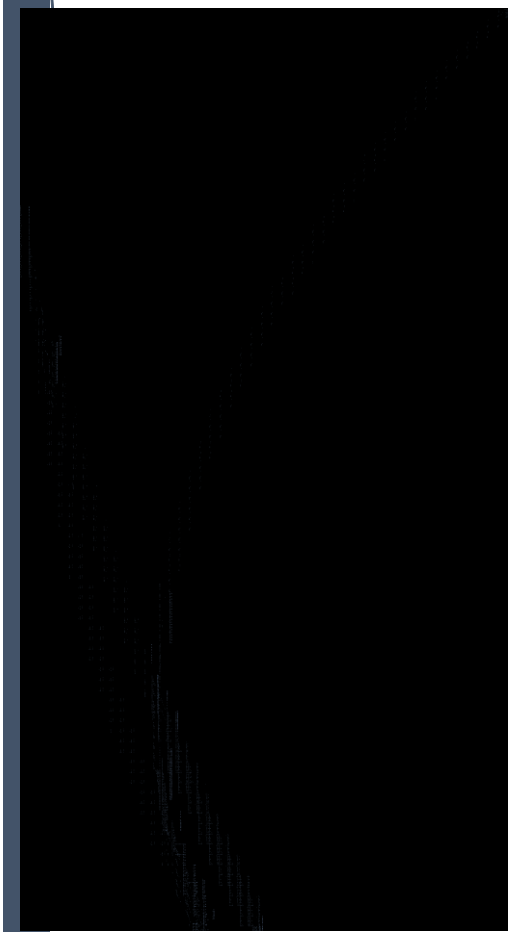
The growth observations like LAR, LWR, LAD, SLA, SLW, AGR, RGR and NAR showed a significant difference among the treatments in *S. macrophylla* and *T. grandis* seedlings. With a few exceptions, seedling growth observations and physiological parameters improved with AMF inoculation. Mycorrhizal inoculations significantly influenced chlorophyll content, photosynthetic rate, transpiration rate, plant water potential, stomatal conductance, relative water content and leaf temperature in *S. macrophylla* seedlings. In case of *T. grandis* seedlings, chlorophyll content, leaf temperature and relative water content were influenced by AMF inoculation. While photosynthetic rate, transpiration rate, stomatal conductance and plant water potential were not influenced by AMF.

The Mycorrhizal Efficiency Index (MEI) in *S. macrophylla* was 66.43 per cent for *F. mosseae* at higher level (50 g inoculum), while in *T. grandis* MUE was 89.23 per cent on *G. proliferum* at higher level (50 g inoculum). Root colonization per cent at lower level (10 g inoculum) was found to range from 15.00 to 24.33 per cent in case of *S. macrophylla*, while it ranged from 34.33 to 55.67 per cent at higher level (50 g inoculums) of inoculation. In *T. grandis,* at lower level (10 g inoculum) root

colonization was found to range from 17.33 to 33.33 per cent, while it ranged from 22.67 to 56.33 per cent at higher level (50 g inoculum) of inoculation.

By looking at overall parameters studied, it can be concluded that *F. mosseae* at 50 g of inoculum at the time of transplanting @ 10 spores /g confers maximum growth and seedling quality benefits in nursery as compared to all other fungi used in for *S. macrophylla*. Seedlings of *T. grandis* with *G. proliferum* at 50 g inoculums performed better in nursery. This technology has the potential to reduce the nursery period and increase in quality of seedlings produced resulting in considerable economic gains.

APPENDICES



APPENDIX - I

Cost of production and maintenance of seedlings in nursery

The total cost for filling 100 polybags using 3:2:1 soil, sand and cowdung mixture in established tree nursery has been estimated at Rs. 140/-. The maintenance charge for 100 polybags in a tree nursery is Rs. 2211/- per year. The expenditure for maintenance of 100 polybags in nursery for one month period is Rs. 185/-. By the inoculation of selected AMF in preferred level the nursery period from one year to five months and we incurred Rs. 185/- per month from 100 polybags. The details were furnished below.

Cost of production of 100 polybag seedlings and maintaining for a period of one year

A. Basic material cost		
Sl. No.	**Items**	**Weight / Price**
1	Red earth	2500/-
2	River sand	6500/-
3	Cowdung (Fresh)	2400/-
4	Cost for one kg polybags	186/-
5	Labour wage per day a. Male b. Female	 450/- 330/-
B. Cost for filling 100 polybags (Commercial production in 3:2:1)		
1	Weight of filled polybags of size 4.5” width x6" length	624g
2	Amount of potting mixture needed to fill 100 polybags	62.4kg
3	Amount of soil required	37.44kg
4	Price of 37.44 kg soil	20.3/-
5	Amount of sand required	12.48 kg
6	Price of 12.48 kg sand	16.07/-
7	Amount of cowdung required	12.48 kg
8	Price of 12.48 kg cowdung	7.14/-
9	Price for 100 polybags	46.5/-
10	Labour charge for filling and transplanting	50/-
C. Maintenance charge for 100 polybags for one year period		
1	Watering (overhead twice in a day)*	51/-
2	Weeding (per month)	600/-
3	Root pruning and ground sheet replacement (per month)	720/-
4	Pesticide spraying **	600/-
5	Supervision and contingency	240/-
	Total amount	**2211/-**

*Pump set and well are placed near ** Ecalex 6 ml per litre in a week

APPENDIX - II

Commercial production of AMF biofertilizer

Arbuscular Mycorrhizal Fungi, being biotrophs, are difficult to cultivate on synthetic media. For bulk production, the natural choice is to develop a dual culture of host roots and AMF. AMF need the symbiotic association with plants for proliferation. Therefore, culturing AM fungi is to inoculate AMF to host plant and to grow the inoculated plant. For the AM fungal inoculums, spores collected form soil can be used. However, spores in soil are not always active in colonizing plants. To isolate AMF colonizing roots, mycorrhizal plants collected from field can also be transplanted to potting medium as Plant Trap Culture. For large scale production of AMF biofertilizer pot culture is followed.

Materials required

1. **Potting medium**: Sterile soil or soil-sand mixture (1:1) is usually used. Various potting materials can be used but the materials for potting medium should be low in available phosphate and preferably not rich in organic matter. In some cases, the fungi isolated from some specific soils may need the specific soil properties for their growth.
2. **Inoculum containing spores and hyphae** (stored moist for less than 7 days at 5^0C)
3. **Plastic pots or grow bags of capacity 5 kg**
4. **2-week-old seedlings as Host plant**: Various mycotrophic plants can be used. Onion, leek (*Allium* spp.), Maize, Rhodes-grass, Sorghum etc. are some of the good hosts. AM fungi generally do not show host specificity but some species show host preference. Therefore, the plant species from which the target AM fungus is isolated can be used as a host plant.
5. **Germination media of vermiculite**
6. **Growth conditions**: Any conditions, which support good growth of host plants, are acceptable. To avoid contamination, a growth chamber is preferable. If greenhouse is used, it should be kept clean. It should be reminded that cross-contamination or contamination from dust is inevitable under open-air

conditions, even in growth chamber. To prevent cross contamination from other pot culture in the same chamber, use plastic bag.

Procedure

125 g of soil inoculum containing spores and hyphae (stored moist for less than 7 days at 5^{o}C) is mixed with soil: sand (1:1) or vermiculite (3G) that has been steam-pasteurized twice over a 24-h period.

Mix is placed into 15-cm plastic pots, and seeds of suitable host are sown.

The soil surface of each pot is covered with sand to a depth of 2 cm to decrease contamination.

The pots are maintained in the greenhouse at approximately 25^{o}C with 14 h of daylight under high-intensity-discharge lights.

Pots are watered from the top when the top 1 cm of the soil surface became dry.

Add Ruakara solution @50 ml per pot at 8 days interval.

Two weeks before harvest, stop irrigation

After 3 months, the plants are cut at the crowns, and spore counts are recorded as described earlier.

Quality standards of mycorrhizal inoculant

Keeping in view of the acceptance of production technology and availability of product in the market, quality control mechanism is needed to ensure consistent quality products to the farmers. Government of India (vide Gazette notification Dated 8th November 2010) has notified the inclusion of mycorrhizal biofertilizer under Fertilizer Control Order (1985).